Geology

MARYLAND GEOLOGICAL SURVEY

CONVERSION OF MEASUREMENT UNITS

Factors for converting English units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English Unit	Multiply By	Metric Unit
feet (ft)	0.3048	meters (m)
gallons (gal)	3.785	liters (L)
gallons per day (gal/d)	3.785	liters per day (L/d)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
gallons per minute per foot [(gal/min)/ft]	0.207	liters per second per meter [(L/s)/m]
inches (in)	25.4	millimeters (mm)
million gallons (Mgal)	3785	cubic meters (m^3)
million gallons per day (Mgal/d)	3785	cubic meters per day (m^3/d)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)

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GROUND-WATER RESOURCES OF HARFORD COUNTY MARYLAND

by

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Prepared in cooperation with the Geological Survey
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GLOSSARY

Anticline. An upfold of layered rocks in the form of an arch and having the oldest strata in the center. The reverse of a syncline.

Anticlinorium. A series of anticlines and synclines so arranged structurally that together they form a general arch or anticline.

Cleavage. A tendency to cleave or split along definite, parallel, closely spaced planes, which may be highly inclined to the bedding planes.

Cross joints. Joints that stike approximately perpendicular to the foliation.

Dip. The angle, in degrees, between a horizontal plane and an inclined plane, measured in a plane perpendicular to the strike.

Fault. A fracture along which the opposite sides have been relatively displaced.

Fluvial. Of or pertaining to rivers.

Foliation. A parallel or nearly parallel structure in metamorphic rocks along which the rock tends to split into flakes or thin slabs.

Fracture cleavage. A capacity to part along closely spaced parallel surfaces of fracture or near-fracture, commonly in a single set, but occasionally in intersecting sets. It is closely related to a joint structure.

Gneiss. A coarse-grained, foliated, metamorphic rock breaking along irregular surfaces and commonly containing prominently alternating layers of light-colored and dark-colored minerals.

Intrusive rock. A rock that is consolidated from molten rock beneath the surface of the earth.

Igneous rock. Rock formed by solidification of molten silicate materials.

Joint. A fracture along which no appreciable movement parallel with the fracture has occurred.

Lenticular. Shaped approximately like a double convex lens. When a mass of rock thins out from the center to a thin edge all around, it is said to be lenticular.

Lithology. The study of rocks based on the megascopic examination of samples.

Mean, arithmetic. A value that is computed by dividing the sum of a set of terms by the number of terms, often referred to as mean or "average."

Median. A value in an ordered set of values below and above which there are an equal number of values.

Metaconglomerate. Metamorphosed conglomerate (coarse-grained, clastic sedimentary rock consisting of fragments larger than 2 mm in diameter).

Metagraywacke. Metamorphosed graywacke (dark, tough, firmly indurated, coarse-grained sandstone consisting of angular to subangular grains of quartz and feldspar embedded in a fine-grained matrix).

Metamorphic rock. A rock formed within the Earth's crust by the transformation of a pre-existing rock in the solid state without fusion and with or without addition of new materials, as a result of high temperature, high pressure, or both.

Metamorphism. The changes, in mineral composition, arrangement of minerals, or both, that take place in the solid state within the Earth's crust at high temperatures, high pressures, or both.

Metasediment. A sedimentary rock that shows evidence of having been subjected to metamorphism.

Micrograms per liter ($\mu g/L$). Metric units for measuring small concentrations of constituents such as iron and manganese in water samples. 1,000 μg/L = 1 mg/L.

Milligrams per liter (*mg/L*). Metric units used for measuring most constituents in water samples. Mg/L is equivalent to parts per million except for high concentrations.

Oblique joint. A joint the strike of which is oblique to the strike of the adjacent strata or cleavage.

Outlier. Part of any stratified group that lies detached or out from the main body, the intervening or connecting part having been removed by denudation.

Paludal. Pertaining to swamps or marshes and to material deposited in a swamp environment.

Pluton. Any body of intrusive igneous rocks.

Saprolite. A residual deposit consisting of decomposed, earthy, untransported material in which the major rock-forming materials other than quartz have been altered to clay. Saprolite usually retains much of the textural and structural characteristics of the igneous and metamorphic rocks from which it is derived.

Schist. A well-foliated metamorphic rock in which the component flaky minerals are distinctly visible.

Schistosity. The variety of foliation that occurs in the coarser-grained metamorphic rocks. Generally the result of the parallel arrangement of platy and ellipsoidal mineral grains.

Serpentinite. A rock consisting almost wholly of serpentine minerals derived from the alteration of previously existing olivine and pyroxene.

Specific capacity (of a well). The rate of discharge of water from the well divided by the drawdown of water level within the well.

Storage coefficient. The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Strike. The compass direction of a horizontal line in an inclined plane.

Strike (*longitudinal*) *joints.* A joint that strikes parallel to the strike of the adjacent strata or foliation.

Syncline. A downfold with troughlike form and having the youngest strata in the center.

Transmissivity. The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Unconformity. A surface of erosion that separates rock strata of different ages.

Well yield. The volume of water per unit of time discharged from a well, either by pumping or by free flow. It is measured commonly as gallons per minute.

GROUND-WATER RESOURCES OF HARFORD COUNTY, MARYLAND

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ABSTRACT

Harford County straddles the Fall Line in northeastern Maryland and is about 80 percent in the Piedmont province and 20 percent in the Coastal Plain province. The Piedmont rocks consist of metamorphosed sedimentary and igneous rocks of Precambrian and early Paleozoic age. The Coastal Plain formations unconformably overlap the Piedmont rocks and consist of unconsolidated sand, gravel, and clay deposits of Cretaceous, Tertiary, and Quaternary age.

Wells in the Coastal Plain sand and gravel aquifers have the potential for yielding more than 500 gal/min in many areas because of the high transmissivity and storage capacity of those aquifers. The Piedmont aquifers have more limited water-yielding potential because water is stored in and transmitted through a highly varied system of fractures in the rock and in the saturated part of the saprolite. Well yields are extremely variable in the Piedmont aquifers, ranging from zero to more than 50 gal/min in most of the aquifers; the Cockeysville Marble probably has the potential for yielding more than 200 gal/min, but it has a small outcrop area. Small to moderate water supplies can be obtained in all sections of the county, although some areas have a fairly significant percentage of wells that are inadequate for household use.

Well yields in the Piedmont aquifers are governed by: geologic structure (joints, faults, cleavage, foliation); topographic position of the wells; lithology; thickness of the saprolite; and well depth. Wells yielding substantially more than the average (based on available well data) can be obtained by judiciously selecting well sites based on hydrogeologic knowledge and by drilling test wells in valleys or draws and along linear features, as mapped on aerial photographs. Data are presented documenting the substantially higher yield for wells drilled along linear features that apparently represent zones of fracture concentration in the rock and for wells drilled in valleys or draws.

The chemical quality of the water in both the Coastal Plain and Piedmont aquifers is generally good. The most common water-quality problems are high concentrations of iron and a low pH. In addition, manganese concentration is high in a few areas in the Coastal Plain, as is that of nitrate in a few areas in the Piedmont.

INTRODUCTION

Purpose and Scope

This 3-year study was an additional segment of a continuing investigation of the hydrogeology of the consolidated-rock aquifers of Maryland by the U.S. Geological Survey in cooperation with the Maryland Geological Survey; in this study, the Harford County Department of Planning and Zoning was also a cooperator. The purpose of the study was to provide information concerning ground-water availability and water quality to planners and health officials in order to assist them in making decisions regarding development of this rapidly urbanizing county. Much of the most rapid suburban development has occurred where public water supplies are not available. As a result, people in these areas have relied on individual wells, which in certain places are not adequate.

Geographic Setting

Harford County is located in northeastern Maryland (fig. 1). It is bounded on the east by the Susquehanna River, on the south by the Chesapeake Bay, on the west by Baltimore County and on the north by York County, Pennsylvania. Approximately 80 percent of the county is in the Piedmont physiographic province, where the landscape is gently rolling to fairly hilly, and is underlain by metamorphic and igneous rocks. The remaining 20 percent is in the Coastal Plain province, where the landscape is gently rolling to flat and is underlain by sand, gravel, and clay. Harford County is drained principally by Broad Creek and Deer Creek, which flow into the Susquehanna River, and by Swan Creek, James Run, Bynum Run, Winters Run, and Little Gunpowder Falls, which flow into the Chesapeake Bay.

Harford County has a land area of 448 mi^2 and had a population of 115,378 in 1970 (U.S. Dept. of Commerce, 1971). The county is still mainly rural, but suburban development has accelerated during the past 10 years, especially in the southwestern part of the county.

The production of mineral resources is limited to a few sand and gravel pits, clay pits, and stone quarries. In addition, a fairly small quantity of talc is produced near Dublin. In past years, slate was quarried near Whiteford, and, during the middle 1800's, chromium ore was mined from some of the serpentinite bodies in the vicinity of Rocks State Park.

Climate

The climate is temperate and moderately humid. The mean annual temperature is 54°F (12.2°C), and the mean annual precipitation is 45 inches,

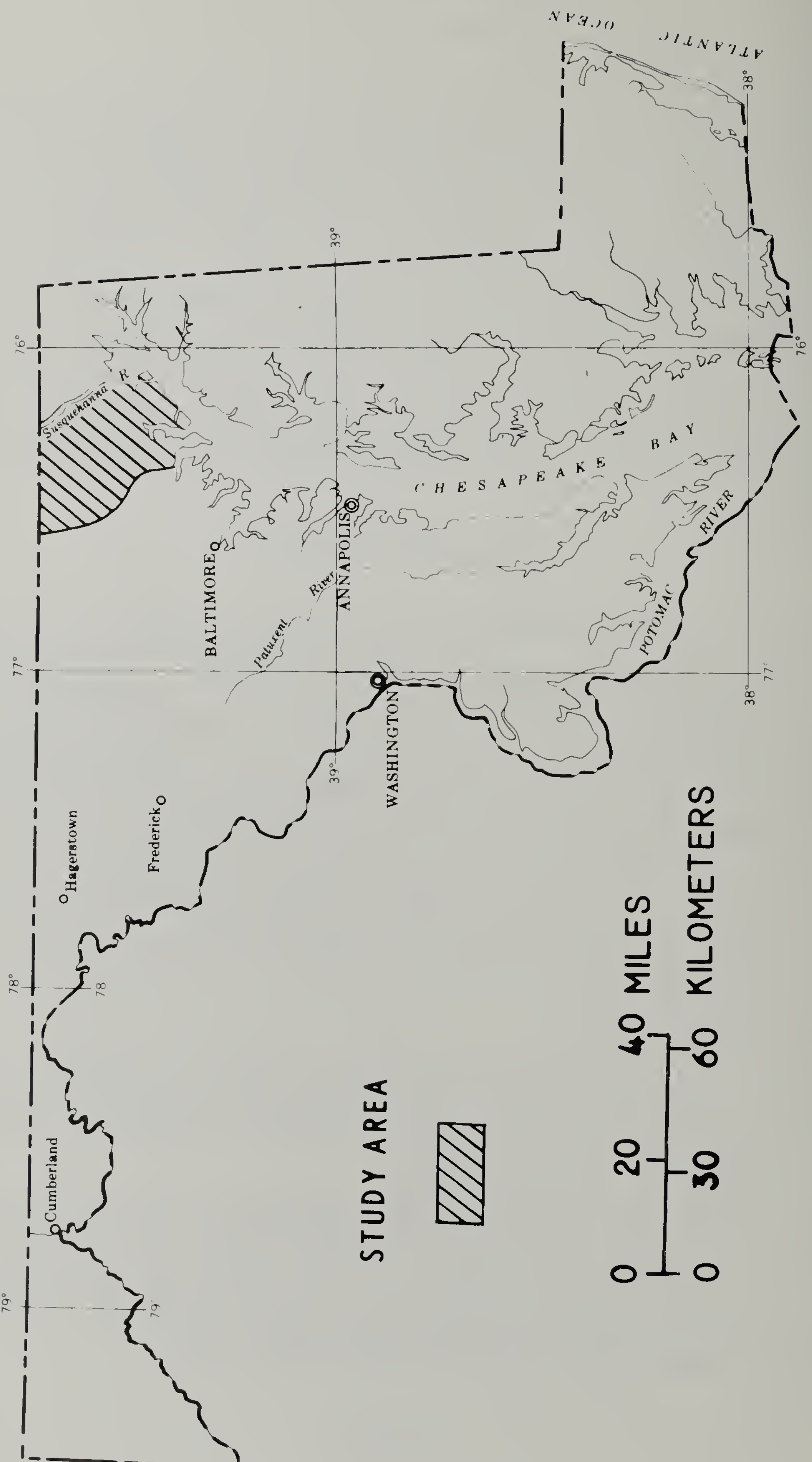

Figure 1.—Area of study.

based on weather records at the Benson Police Barracks, Aberdeen Proving Ground (Phillips Field), and Conowingo Dam. Precipitation is fairly evenly distributed throughout the year, but is somewhat greater during the summer.

Ground-water runoff in the Little Gunpowder Falls basin, draining parts of Baltimore and Harford Counties, was found to be 11 inches per year, or 27 percent of the average annual precipitation (Dingman and Ferguson, 1956). Over a long period of time, recharge must equal ground-water runoff. Therefore, recharge in the Little Gunpowder Falls basin is about 540,000 gallons per day per square mile. This figure compares favorably with the results obtained in other studies in Piedmont areas and can probably be applied to the entire Harford County Piedmont.

Methods of Investigation

During the initial 2 years of the study, records were obtained for more than 1,100 wells and 115 ground-water samples collected for chemical analysis. These data and more than 100 heretofore unpublished well records from the files of the U.S. Geological Survey and 25 chemical analyses from previously published reports are included in a basic-data report for Harford County (Nutter and Smigaj, 1975).

Ground-water availability on a countywide scale and within individual housing subdivisions was studied, and factors governing well yields (topographic position, well depth, lithology, and geologic structure) were evaluated. Linear-feature mapping was used experimentally to select well sites where high yielding wells are likely. Linear features were mapped on topographic maps, aerial photos, and side-looking radar imagery. Three test wells were drilled using these methods for selecting well sites. The specific capacities of wells located on linear features were compared with the specific capacities of all wells in two quadrangles selected for more intensive study.

The Bel Air and Jarrettsville 7½-minute quadrangles were selected for preparation of hydrogeologic atlases, which include maps describing ground-water availability, land slope, depth to water table, and septic-tank constraint (Nutter, 1977a and 1977b).

Water-level measurements were made in eight observation wells established during the study, and records from three long-term observation wells were also available.

Ground-water quality was studied, with emphasis on those constituents that affect use. Several cases of high nitrate concentration were studied to determine their probable source. Field pH and specific-conductance measurements were made when most water samples were collected.

Well-Location System

Wells in Maryland are identified and can be located on the basis of a numbering system adopted by the Maryland Geological Survey. The first two letters of the identification number are the county prefix; for example, for Harford County the prefix is HA. The second two letters in the identification number designates one of the 5-minute quadrangles of latitude and longitude into which the county has been divided. Each quadrangle from north to south is designated by the first letter, and from west to east by the second letter. The wells are numbered in sequential order within each 5-minute quadrangle. Thus, HA-BC 45 is the 45th well inventoried in the BC 5-minute quadrangle.

Acknowledgments

Well drillers were very helpful in providing data. Industrial and commercial property owners and homeowners were helpful in supplying well data and permitting measurements to be made and water samples to be collected. Special thanks are given the Harford County Health Department, Division of Sanitation, for supplying well data, percolation-test data, and water-quality data from their files. Whitman, Requardt and Associates supplied well data and chemical analyses of water samples from the Aberdeen and Joppatowne areas. The Harford County Board of Education and the Maryland Park Service were helpful in permitting test wells to be drilled on their property.

GEOLOGIC SETTING

General Features

About 80 percent of Harford County is in the Piedmont province and is underlain by metamorphic and igneous crystalline rocks of Precambrian and early Paleozoic age.[1] The remaining 20 percent is in the Coastal Plain province and is underlain by unconsolidated sand, gravel, and clay of Cretaceous, Tertiary, and Quaternary age which unconformably overlap the crystalline Piedmont rocks. The geology of the two provinces is markedly different, and this difference is reflected in the water-bearing characteristics of the rocks. In the Piedmont, water occurs in fractures and other secondary openings in the rocks, whereas in the Coastal Plain, it occurs in the intergranular pore space.

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[1] The stratigraphic nomenclature used in this report is that of the Maryland Geological Survey and does not necessarily follow the usage of the U. S. Geological Survey.

Coastal Plain

Coastal Plain sediments overlie the crystalline rock in parts of southern Harford County. The Coastal Plain formations dip gently south-eastward and thicken in that direction. The deposits include the Potomac Group of Cretaceous age, the upland gravel deposits of probable Pliocene (Tertiary) age, and the Talbot Formation of Pleistocene (Quaternary) age (fig. 2). In addition, alluvial deposits consisting of brown silt and clayey sand occur in many of the major stream valleys.

The Potomac Group crops out over extensive areas in the southern part of the county north and west of Bush River and underlies the Talbot Formation in most other parts of the Coastal Plain. The Potomac Group consists of light-colored sand, gravel, and red, white, and gray clay that was deposited in a continental environment (fluvial, channel fill, overbank, paludal) (Owens, 1969, p. 91). The sand and gravel beds are lenticular, and their thickness and lateral extent change rapidly within fairly short distances. The Potomac Group deposits dip to the southeast and thicken fairly rapidly downdip. These deposits tend to be gravelly at the base (Patuxent Formation in Baltimore and Anne Arundel Counties), clayey in the middle part (Arundel Formation), and sandy and clayey at the top (Patapsco Formation). However, Owens (1969, p. 81) does not feel the Potomac Group can be clearly separated into the Patuxent, Arundel, and Patapsco in Harford County based on lithology.

The upland gravel deposits consist of poorly sorted brown to red gravel, sand, silt, and clay. They occur as isolated outliers capping the higher hills within a zone about 3 miles wide northwest of the other Coastal Plain deposits; they are apparently of fluvial origin (Owens, 1969).

The Talbot Formation consists of yellow to brown sand, gravel, clay, and silt. Owens separated the Talbot into two lithofacies: a lower thick-bedded, cross-stratified gravelly sand facies and an upper massive to thin-bedded, very clayey silt or silty clay. The gravelly sand facies is absent over wide areas of Talbot Formation outcrop; it seems to be thickest and coarser grained in the Perryman, Aberdeen, and Havre de Grace areas. Where the gravelly sand facies is present, its thickness ranges from a few feet to more than 100 ft. The silt-clay facies is much more extensive than the gravelly sand facies, but is generally less than 20 ft. thick (Owens, 1969, p. 97).

Piedmont

The Piedmont rocks consist of intensely deformed schist, gneiss, metagraywacke, slate, and mafic rocks (chiefly gabbro). The original sedimentary and volcanic rocks have been intensely folded, faulted, metamorphosed, and intruded by mafic and granitic plutons (Southwick, 1969, p. 3). The intrusive rocks have themselves been deformed and metamorphosed. However, Crowley (1976) believes that the mafic and granitic rocks

that Southwick interprets as plutons have actually been overthrust from the southeast to their present position.

The major geologic structures in Harford County include the Baltimore-Washington anticlinorium, the Phoenix dome, and the Peach Bottom syncline (fig. 2). The dominant foliation in the metasedimentary rocks is parallel to the bedding. However, in some places, especially where the beds are tightly folded, a discordant axial-plane cleavage and schistosity is superimposed (Southwick, 1969, p. 9).

Faults

The four major faults mapped by Southwick (1968) are all parallel to the strike of the bedding and major foliation. They include: (1) A fault connecting several ultramafic-rock bodies in the northwest part of the county, (2) the Mill Green fault forming the southern boundary of the metaconglomerate at Rocks Ridge and trending northeastward, (3) a fault forming the western boundary of the Baltimore Gabbro near the Baltimore County line, and (4) a fault near the center of the James Run Gneiss outcrop north of Abingdon. The Mill Green fault forms a prominent linear feature several miles in length on Landsat photographs and side-looking radar imagery.

Many additional faults are almost certainly present, but are difficult to map in the poorly exposed and complex metamorphic rocks of the Maryland Piedmont.

Joints

Joints can be observed in any deep road cut or quarry in the Piedmont. Joints in a parallel array constitute a joint set, and in nearly all areas in the Maryland Piedmont there are two or more joint sets forming a joint system. In the Maryland Piedmont, the most frequently occurring joint set is normally the cross-joint set, which is approximately at right angles to the strike of the foliation or schistosity (Cloos, 1937). The strike-joint set, the second most frequently occurring set, is parallel to the foliation and is therefore approximately at right angles to the cross joints. Oblique joints, which form a third category of joint sets, form at angles of approximately 45° to the strike joints, but this angle varies, depending to a large extent on the lithology (Cloos, 1937, p. 75). In many places, other less prominent joint sets are also found. A subsequent section of this report presents some specific data regarding joint orientations.

WELL YIELDS AND SPECIFIC CAPACITIES

Well yields and specific capacities in the Piedmont aquifers are characterized by extreme variability; well yields and specific capacities in the

Coastal Plain aquifers also vary widely, but wells in the Coastal Plain have generally larger yields. On the basis of the well-yield data assembled for this study, the aquifers in Harford County were grouped into five generalized hydrogeologic units, the same as those identified in the Bel Air and Jarrettsville atlases (Nutter, 1977a and 1977b). Figure 3 shows the approximate areal distribution of the five hydrogeologic units. The relative water-yielding properties of these hydrogeologic units are shown by the specific capacity graphs in figure 4. Table 1 lists the geologic formations contained in each hydrogeologic unit. These formations are listed in approximate order of productivity based on available well data. However, for a few formations, the data are insufficient to determine the water-bearing properties with confidence.

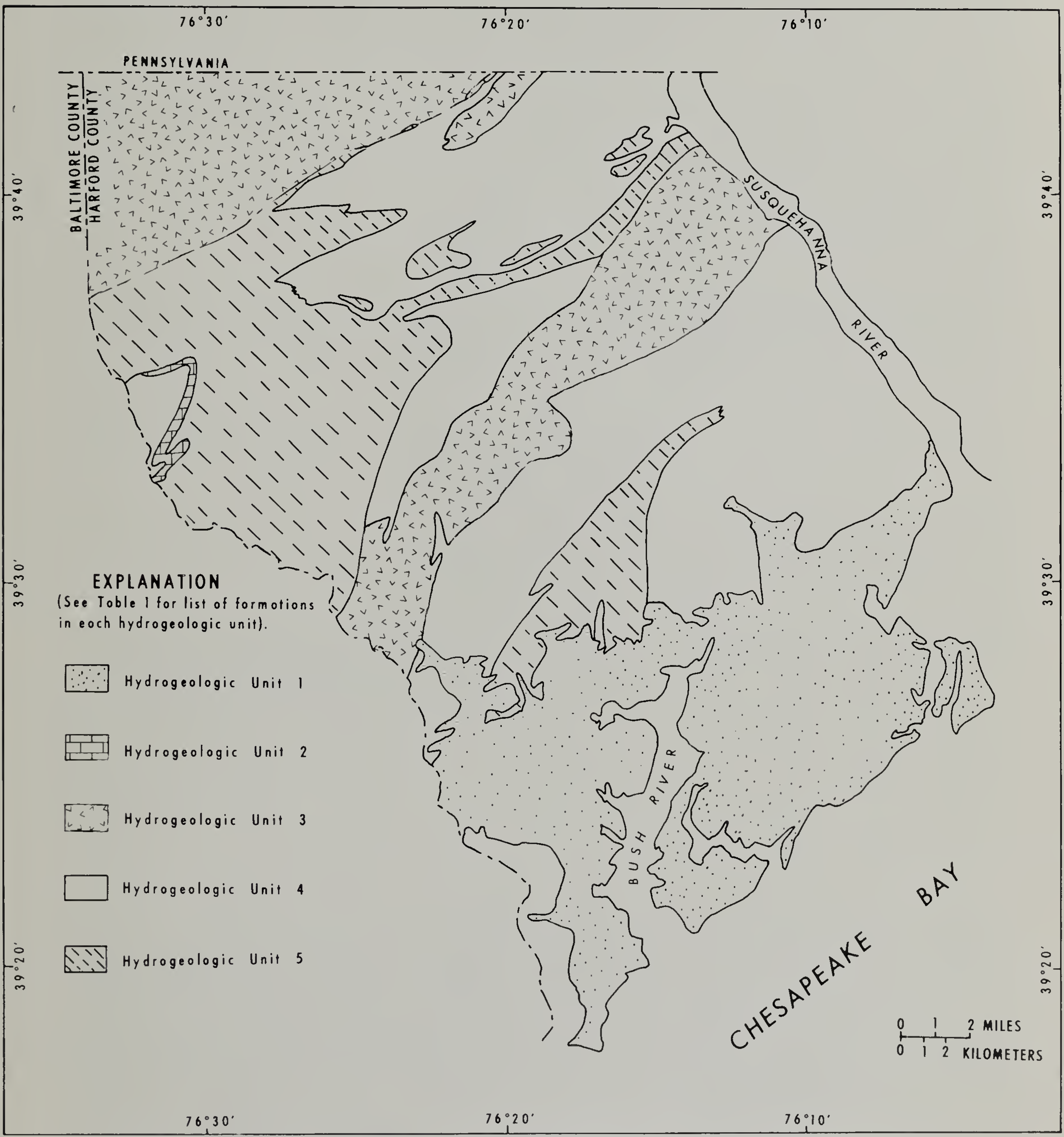

Figure 3.—Approximate areal distribution of hydrogeologic units.

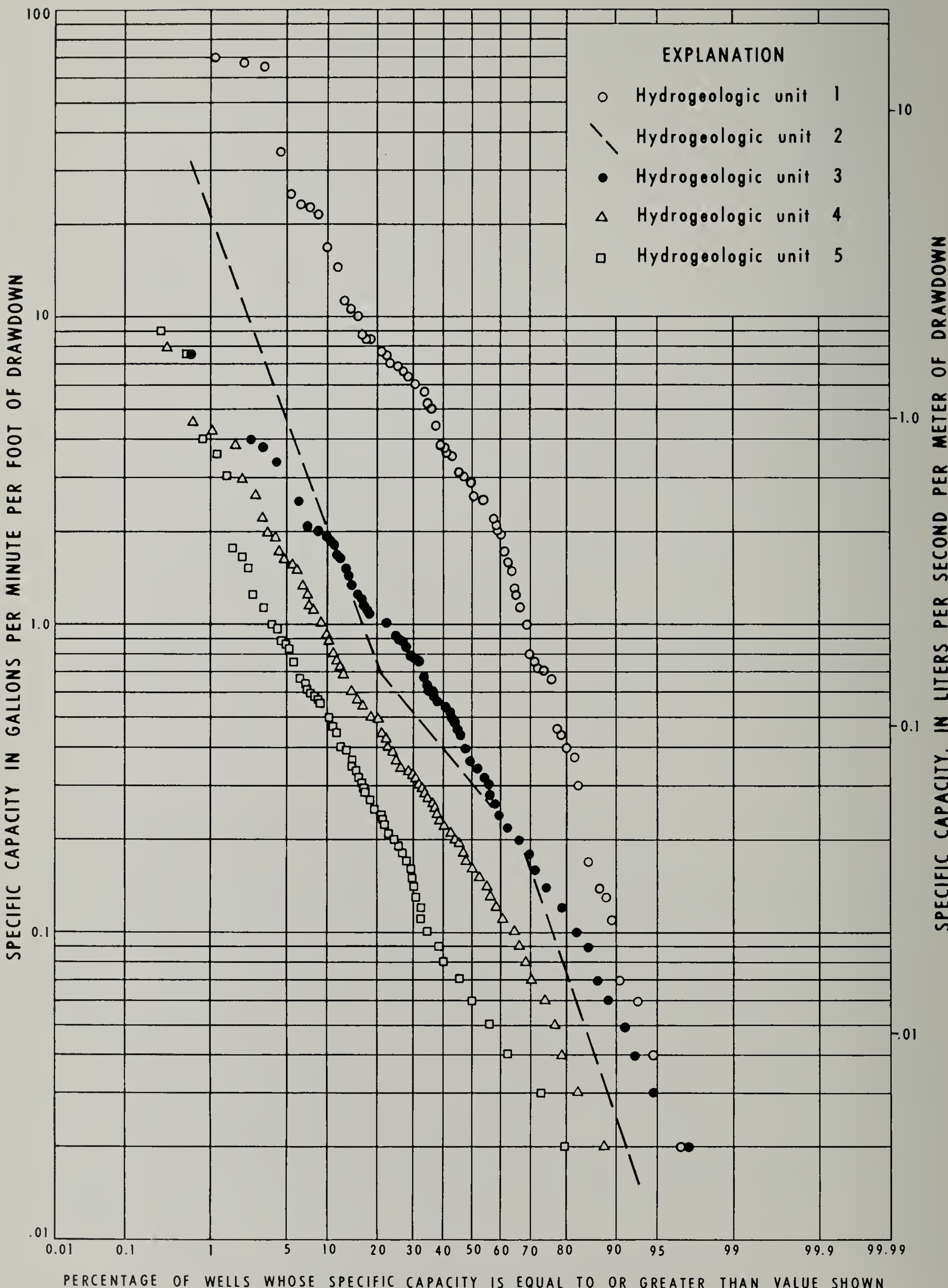

Figure 4.—Relation between the specific capacities of wells in five hydrogeologic units.

Table 1.—Geologic formations contained in the five hydrogeologic units (formations are listed in approximate order of productivity).

Hydrogeologic unit 1	Talbot Formation Potomac Group
Hydrogeologic unit 2	Cockeysville Marble
Hydrogeologic unit 3	Upper pelitic schist of Wissahickon Formation Baltimore Gabbro Quartz gabbro and quartz diorite gneiss Cardiff Metaconglomerate Peach Bottom Slate
Hydrogeologic unit 4	Port Deposit Gneiss Wissahickon Formation undivided Boulder gneiss of Wissahickon Formation Metagraywacke of Wissahickon Formation Baltimore Gneiss Muscovite quartz monzonite gneiss Metaconglomerate of Wissahickon Formation Metagabbro and amphibolite
Hydrogeologic unit 5	James Run Gneiss Ultramafic rocks[1] Setters Formation Lower pelitic schist of Wissahickon Formation Amphibolite (associated with Wissahickon Formation undivided)[2].

[1] Includes ultramafic and gabbroic rocks.
[2] Not mapped as separate unit on figure 2.

The well-yield data used to construct figure 4 were from Harford County, except for the Cockeysville Marble data (unit 2), which were from adjacent parts of Baltimore County (Laughlin, 1966). Well data from Baltimore County were used because few wells have been drilled in Harford County in the small area underlain by the Cockeysville Marble. However, it is likely that the water-yielding properties of the Cockeysville Marble are similar in Baltimore and Harford Counties.

Hydrogeologic Unit 1

The Coastal Plain aquifers (hydrogeologic unit 1) are clearly much more productive than the Piedmont aquifers (hydrogeologic units 2-5). The median specific capacity of hydrogeologic unit 1 is 2.8 (gal/min)/ft; whereas the median specific capacities of hydrogeologic units 2-5 range from 0.36 to 0.06 (gal/min)/ft.

Hydrogeologic unit 1 is composed of alternating layers of sand, gravel, and silty clay. The sand and gravel layers form aquifers that readily yield water to wells. The silty clay layers form confining beds that generally will not yield sufficient water for most uses because the pore spaces are so small that water is retained by capillary forces. The thickness and areal extent of individual sand and gravel beds in the Harford County Coastal Plain are extremely variable and difficult to predict, but some aquifer material is present in nearly all areas. Where the sand and gravel deposits are thick and permeable, wells yielding several hundred gallons per minute can be developed; in areas where the sand is thin, yields of only a few gallons per minute may be possible.

A map of the approximate thickness of Coastal Plain deposits (fig. 5) can provide a general guide to drilling test wells. Areas having thick Coastal Plain deposits coincide, at least in some areas, with thick and permeable sand and gravel deposits (Perryman well field, for example).

Hydrogeologic Unit 2

Hydrogeologic unit 2 consists of the Cockeysville Marble. The relative productivity of units 2 and 3 are in some respects fairly similar (fig. 4). Unit 2 has higher specific capacities only in the highest 10 percent of the wells for which data are available; the median specific capacity of the two units is similar. Nevertheless, the Cockeysville Marble was ranked above hydrogeologic unit 3 because of the greater probability of obtaining wells with high specific capacities in the marble (fig. 4).

The data points for the Cockeysville are not plotted on figure 4 in order to emphasize that the Cockeysville graph is based on data from Baltimore County.

Hydrogeologic Units 3-5

The formations constituting these units include diverse lithologies, with little sharp distinction in water-yielding properties between any two formations. Differences in water-yielding properties between formations appear to be related to the lithology and the geologic structure (jointing, faulting, cleavage, and foliation). The factors governing well yields and specific capacities are discussed in another section of this report.

Table 1 provides a generalized ranking of the water-yielding properties of hydrogeologic units 3, 4, and 5. The slope of the graphs in figure 4 shows the extreme variability of specific capacity within each unit. The reader should recognize that these hydrogeologic units are valid only for broad planning purposes and that all available data relating to a specific site should be evaluated before making a judgment concerning the ground-water availability at the site.

Evaluation of Well Data

Most of the well data used to prepare this report are reported data based on drillers' completion reports filed with the Maryland Water Resources Administration. These well records are probably basically accurate, but it is important to recognize some of the circumstances relating to the collection of these data. One important point is that nearly 75 percent of the well records in the Harford County Basic Data Report (Nutter and Smigaj, 1975) pertain to domestic wells. Domestic well sites are mostly selected for convenience and are seldom located at the most favorable site. In addition, domestic wells are usually drilled to a depth where only the amount of water required (3 to 10 gal/min) is obtained; domestic wells drilled at favorable sites would likely have yielded considerably more water if drilled to depths of 250 or 300 ft. Moreover, most deep domestic wells are drilled at unfavorable sites, and many of these deep wells have insufficient yields for even domestic use.

Consequently, estimates of potential well yields based on the available well records may be distorted. This has been pointed out by several hydrologists (Poth, 1968; Cederstrom, 1972; Nutter, 1974). A more realistic method for estimating the potential yield of wells drilled under optimum conditions might involve computing a median yield from among the more productive wells (perhaps the upper 10 percent) as an estimate of the expected well yields.

Best results for developing maximum well yields are likely to be obtained if well sites are selected using existing geologic and hydrologic data, and test wells are drilled to a depth of about 300 ft. A few exploratory test wells might be necessary before a high-yielding production well is obtained. When drilling wells in housing subdivisions, the choice in well sites is usually restricted to a fairly small area of the building lot. On many lots, particularly in areas with a history of well-yield problems, there may not be a favorable site for drilling a well anywhere on the lot.

FACTORS AFFECTING WELL YIELDS

Coastal Plain Aquifers

In the Coastal Plain deposits, well yields are governed by the permeability, thickness, and lateral extent of the sand or gravel beds in which

the wells are screened. In addition, to a much greater extent than in the Piedmont aquifers, the yield of wells in the Coastal Plain aquifers is dependent on well-construction factors, such as length of screen, type of screen, diameter of well, whether the screen is placed in the most permeable zone of the aquifer, how efficiently the well is gravel packed, and how thoroughly the well is developed to remove fine material that may clog the aquifer around the well screen. The intended water use indirectly affects reported well yields, probably to an even greater extent in the Coastal Plain aquifers than in the Piedmont aquifers. For example, domestic wells in Coastal Plain aquifers are seldom reported to yield more than a few tens of gallons per minute, as this amount is sufficient for domestic use. However, larger yields would have been possible with proper screening and development. Wells in the Coastal Plain aquifers have the potential for yielding more than 500 gal/min in many areas.

Piedmont Aquifers

The availability of water in crystalline-rock aquifers ultimately depends on the distribution of secondary openings, such as joints, faults, and cleavage planes. Wells must intersect some of these secondary openings to yield water. The principal factors that govern well yields and specific capacities include the following: Geologic structure, topographic position, lithology, thickness of saprolite, and well depth. Well yields are extremely variable in the Piedmont aquifers because of the variable nature of the secondary openings. Reported yields in Harford County range from 0 to 140 gal/min.

Geologic Structure

The geologic structure is the most important factor governing well yields and specific capacities in crystalline-rock aquifers. Geologic structure includes joints, faults, cleavage, foliation and schistosity.

Joints are probably the most common secondary openings through which ground water moves, and therefore their distribution is most important in determining ground-water availability. Joints almost always occur in two or more sets of subparallel planes forming a system of intersecting joint planes.

Predicting where a well will intersect joint planes is difficult because the bedrock is almost everywhere concealed by a mantle of saprolite. However, the stream network in the Piedmont part of Harford County seems to be largely controlled by the joint system (fig. 6). Therefore, mapping linear features, such as straight stream reaches on aerial photographs, can be useful for predicting where wells are most likely to intersect joint planes. Because most joint planes

Figure 6.—Closely spaced joints controlling stream direction.

are steeply dipping, the surface expression of them provides a good indication of their location at moderate depths. Of course, some linear features result from faults, foliation, or other structural or lithologic features. The relationship between linear features and the availability of ground water will be discussed in another section of this report.

The joint spacing (distance between adjacent joint planes) has an important bearing on ground-water availability and is related to major structural features (such as the position on an anticline or the distance from a major fault) and to the lithology. In general, schistose rocks tend to be sparsely jointed compared to equigranular rocks, such as gneiss or granite. In the quarry at Port Deposit, where the Port Deposit Gneiss is quarried, the average joint spacing (on a horizontal plane) seems to be 8.5 ft., on the basis of computations made using data by Hershey (1937, plate 17). The joint spacing at the Davis quarry near Churchville, where the James Run Gneiss is quarried, seems to be 7 ft, but is 1 or 2 ft in a few places along James Run near the quarry. Data on joint spacing are difficult to obtain in schistose rocks because they are seldom exposed in quarries. In many areas underlain by the lower pelitic schist of the Wissahickon Formation, the joints are inferred to be widely spaced because of the high proportion of low-yielding wells.

Faults are also secondary openings in which ground water is stored and through which it moves. Faults are less numerous than joints in the Harford County Piedmont, but certainly more numerous than shown on available geologic maps. Some of the longer, more prominent linear features observed on aerial photographs, Landsat imagery, and side-looking radar imagery, apparently delineate fault traces. Fault zones may be favorable sites for drilling test wells where high yields are sought because, in addition to the possibility of intersecting the principal fault plane, the rock in the vicinity of the fault may be intensely fractured.

Available well data suggest that wells drilled near known fault traces have higher average yields than the average of other wells in the area. Of the wells whose records are available, 15 are within 100 ft of the trace of the Mill Green fault (fig. 2). In addition, two test wells were drilled near the fault mapped by Southwick (1969, p. 6) near Fallston. Table 2 lists some pertinent data relating to these wells.

The mean yield of these wells is 14.4 gal/min, and the mean specific capacity is 0.94 (gal/min)/ft. These data compare with an average yield of 10.2 gal/min and an average specific capacity of 0.31 (gal/min)/ft for all the wells within the BA, BB, and CC 5-minute quadrangles. Yields and specific capacities of three of the wells listed in table 2 (HA-BB 28, -BA 55, and -BA 58) are among the highest for Piedmont wells drilled in Harford County (fig. 4).

In rock types in which cleavage is well developed (such as in slate and phyllite), cleavage planes may be important secondary openings affecting water availability. In fact, at some rock exposures, it is difficult to distinguish closely spaced joint planes from cleavage planes.

Table 2.—List of wells within 100 ft of major faults (Mill Green fault and a fault near Fallston).

Well number	Yield (gal/min)	Specific capacity [(gal/min)/ft]	Aquifer
	(MILL GREEN FAULT)		
HA-BB 26	15	0.50	Lower pelitic schist.
HA-BB 28	17	4.25	Metaconglomerate.
HA-BB 65	1	.01	Metagraywacke.
HA-BB 88	2	.02	Lower pelitic schist.
HA-BB 94	2	.01	Do.
HA-BB 96	15	.15	Metaconglomerate.
HA-BA 55	32	3.56	Lower pelitic schist.
HA-BA 58	18	3.60	Do.
HA-BA 59	25	.76	Do.
HA-BA 60	10	.25	Do.
HA-BA 61	5	.07	Do.
HA-BA 62	6	.09	Do.
HA-BA 63	2	.02	Do.
HA-BA 72	10	.30	Do.
HA-BA 73	12	.50	Do.
	(FAULT NEAR FALLSTON)		
HA-CC 142	28	.62	Baltimore Gabbro.
HA-CC 143	45	1.22	Do.
Average of 17 wells	14.4	0.94	

Topographic Position

The important effect of topographic position on well yields has long been recognized (LeGrand, 1949; Dingman and Ferguson, 1956; Poth, 1968; Nutter and Otton, 1969). Nearly all authors agree that higher yields are obtained from

wells in valleys and draws than from wells on hillsides and hilltops. Well yields in valleys and draws are apparently higher than those on hilltops and hillsides because the location of topographic lows is, to a considerable extent, controlled by the geologic structure. The joint system is probably the single most important factor controlling the location of valleys and draws; therefore, wells drilled in valleys are more likely to intersect major joint planes than wells drilled elsewhere. However, lithologic variations (some very subtle) are also factors controlling the orientation of valleys and draws.

Figure 7 is a frequency graph showing the distribution of specific capacities of a sample of about 200 wells separated into the following three categories: (1) Valleys and draws, (2) hillsides, and (3) hilltops. The wells in valleys are substantially more productive than wells on hilltops and hillsides, but there is not as much difference between the specific capacities of wells on hilltops compared with wells on hillsides.

The following table contrasts the specific capacities and yield of wells by topographic position:

	Valleys and draws	Hillsides	Hilltops
Median specific capacity	0.39 (gal/min)/ft	0.18 (gal/min)/ft	0.10 (gal/min)/ft
Mean specific capacity	1.17 (gal/min)/ft	0.21 (gal/min)/ft	0.20 (gal/min)/ft
Median reported yield	15 gal/min	9.0 gal/min	6.0 gal/min
Mean reported yield	20 gal/min	10 gal/min	9.0 gal/min
Number of wells in sample	34	59	89

The three categories in the preceding table include wells in schist, gneiss, gabbro, slate, metaconglomerate, metagraywacke, and quartzite. It is concluded that the topographic position of a well site is very important where maximum yields are sought. Wells drilled in valleys and draws are likely to have substantially higher yields than wells drilled on hilltops or hillsides.

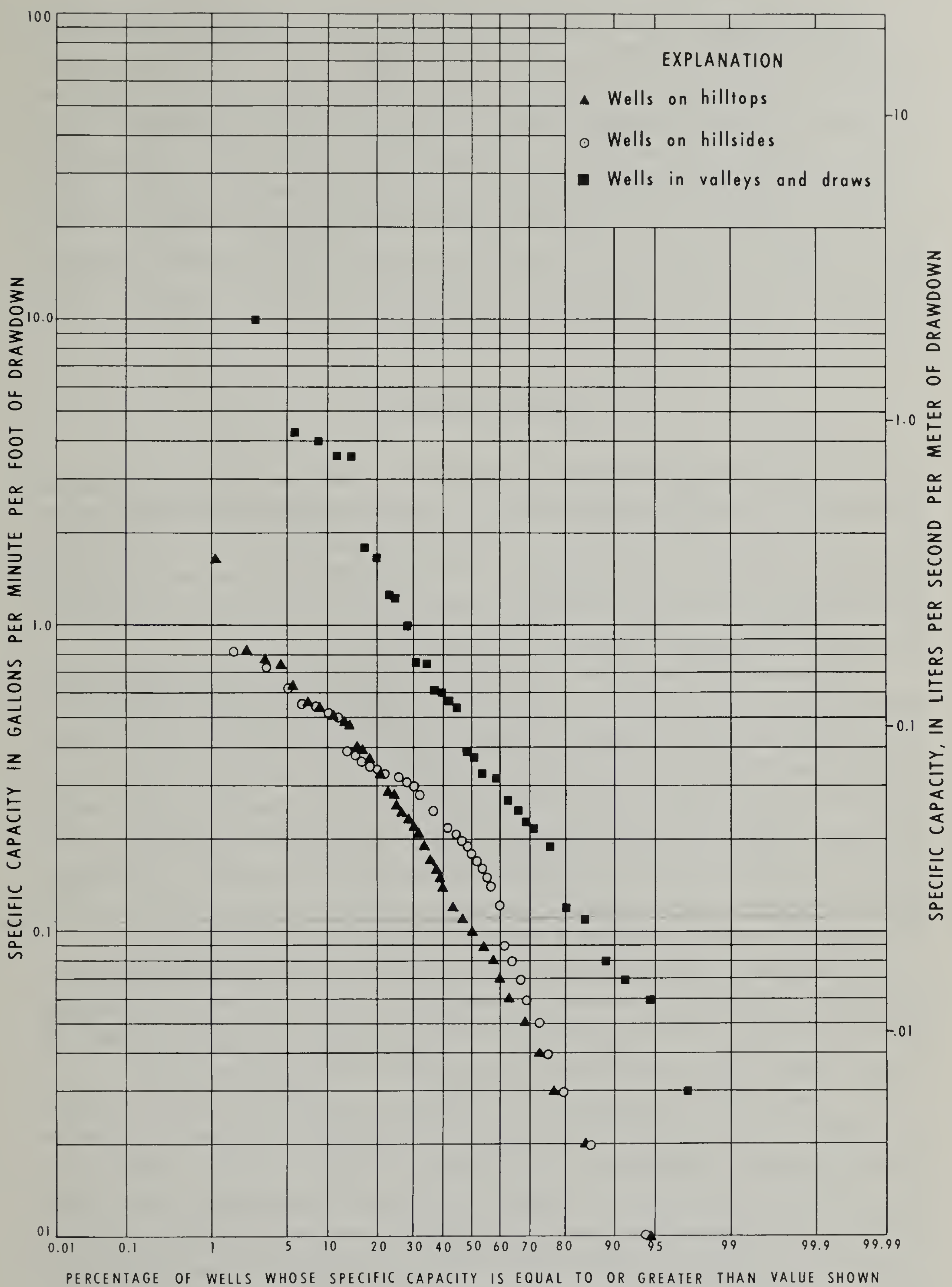

Figure 7.—Relation between yield of wells in valleys, on hillsides, and on hilltops. (All wells shown tap Piedmont aquifers.)

Lithology

The lithology of the Piedmont aquifers also controls ground-water availability. Different crystalline-rock formations seem to have fairly distinct water-bearing properties, in spite of complexities such as more than one lithologic type being included within a formation. The best example of the effect of lithology is probably the Cockeysville Marble. The water-bearing properties of the Cockeysville Marble are generally superior because solution along the fractures has substantially increased the permeability in many places. Figure 8 contrasts the specific capacities of the principal Piedmont formations. A few of the aquifers are not included in figure 8 because of their small areal extent and scarcity of well data.

Saprolite Thickness

The Harford County Piedmont is covered by a mantle of saprolite of varying thickness. The saprolite was formed by in-place chemical weathering, and in most places the relic structure of the parent rock can be observed. The thickness, porosity, and permeability of the saprolite are important factors determining ground-water availability because much of the water is stored in the part of the saprolite below the water table.

The nature of the saprolite depends to a large extent on the lithology of the parent rock, but, in general, the saprolite is a clay-rich residual deposit. It is normally characterized by high porosity, but fairly low permeability. Several studies have indicated that the permeability of the saprolite tends to be greatest near the contact with the underlying bedrock (Stewart, 1964; Nutter and Otton, 1969). The change from saprolite to unweathered crystalline rock is gradational, and normally the contact between them is not sharp. The porosity of the saprolite may exceed 50 percent, whereas the porosity of the unweathered rock is less than 5 percent (chiefly fracture porosity).

The thickness of the saprolite can be approximated by the length of casing reported by well drillers because the casing is normally installed after drilling only a few feet of unweathered rock. The thickness of saprolite in Harford County ranges from a few feet to about 100 ft and averages 42 ft.

The nature and thickness of the saprolite affects the yield of wells, particularly the sustained yield during dry periods, but direct correlation between saprolite thickness and well yields is difficult to prove. Many wells tapping thick saprolite have low yields, but, where the saprolite is thick, wells appear to have higher than average yields. The saprolite thickness can be expected to be greater in zones where joints and faults are closely spaced; in fact, weathering may occur to considerable depths adjacent to fractures. Mapping saprolite thickness using geophysical methods (such as seismic refraction) has been used to locate probable zones of fracture concentration

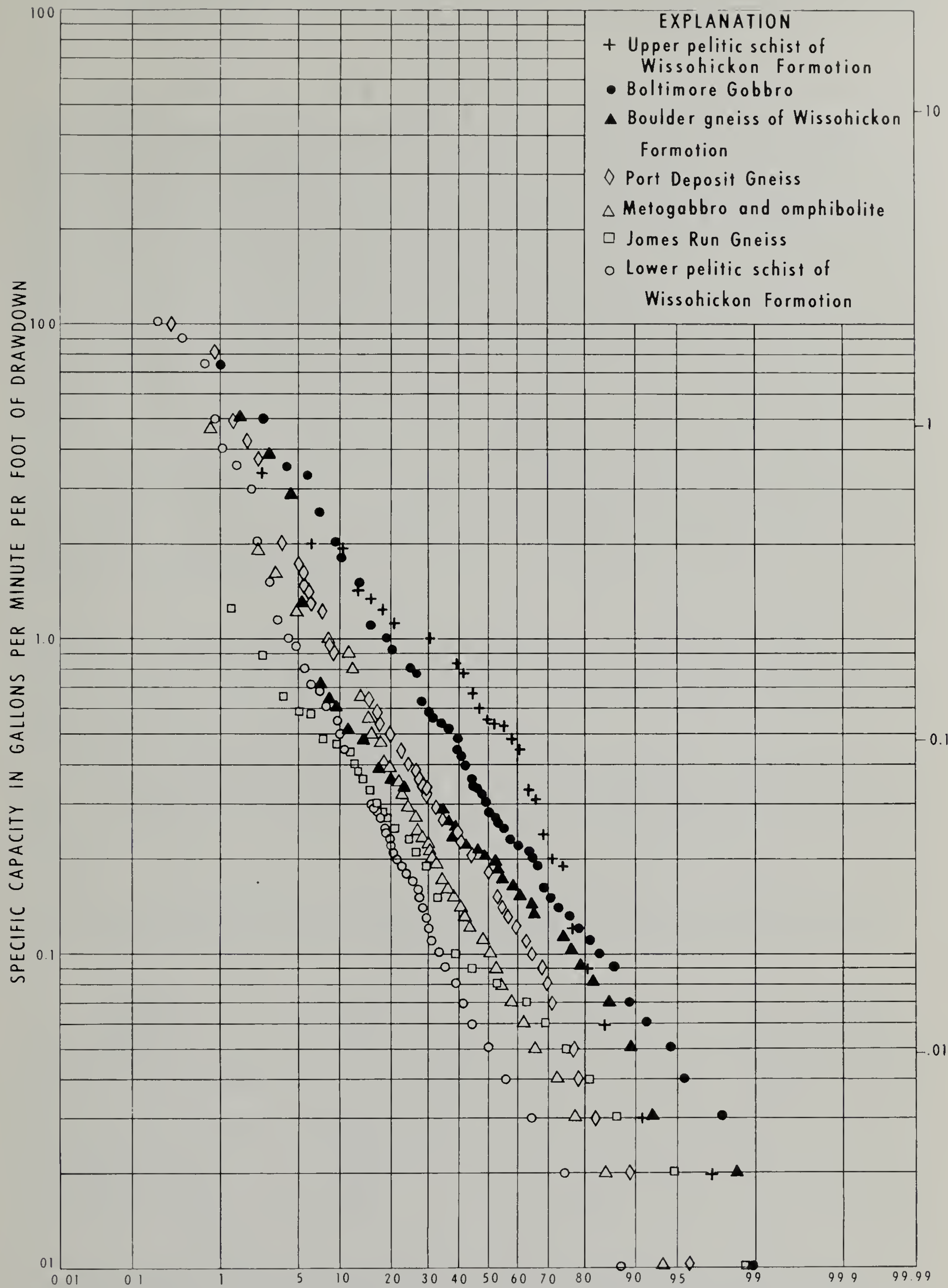

Figure 8.—Frequency graph showing specific capacities of wells in Piedmont aquifers.

(Joiner and others, 1967). These procedures appear promising, but they are expensive and further investigation is needed to test them adequately.

Well Depth

Available data suggest that well yields are not likely to be increased substantially by drilling deeper than about 300 ft in Piedmont aquifers because fractures apparently become progressively more widely spaced with increasing depth, and the width of openings become smaller because of increasing overburden pressure. There are undoubtedly exceptions to this general statement; however, the overwhelming amount of well data in the Maryland Piedmont indicate that nearly all water-bearing fractures are less than 300 ft deep. Note, however, that the data may be somewhat biased because nearly all wells deeper than about 200 ft in the Harford County Piedmont are domestic wells that did not yield sufficient water at a shallower depth. In most cases, deepening these unfavorably located wells has resulted in only slight, if any, improvement in yield. Consequently, the average yield is 7.3 gal/min for wells deeper than 249 ft and 6.1 gal/min for wells deeper than 299 ft, compared with the average yield of 12 gal/min for all Piedmont wells in Harford County.

Domestic wells drilled at favorable sites, such as in valleys and draws, usually obtain sufficient water for household use at shallow depths and are seldom drilled deeper than 150 ft. Therefore, the well data contain a bias that is difficult to evaluate because few wells at favorable sites have been drilled deeper than 300 ft. Nevertheless, the data suggest that even at favorable sites, most water-bearing fractures are within 300 ft of the land surface.

RELATION BETWEEN LINEAR FEATURES AND GROUND-WATER AVAILABILITY

The complex system of joints and faults that transmits ground water in the Harford County Piedmont also controls the stream network to a considerable extent. Therefore, mapping straight stream reaches and other linear features on aerial photographs can be a useful tool in selecting sites where wells are likely to have high yields. Several hydrogeologists have used the technique of mapping linear features or "fracture traces" as a prospecting tool for selecting well sites (Lattman and Parizek, 1964; Woodruff and others, 1974; McGreevy and Sloto, 1977). Lattman and Parizek (1964) defined a fracture trace as a ". . .natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tonal alignments, visible primarily on aerial photographs, and expressed continuously for less than one mile." The term "lineament" was used by Lattman and Parizek to refer to linear features of more than 1 mile in length. Throughout this report the term "linear feature" is

used rather than "fracture trace" for short features because linear features can result from phenomena other than fractures (for example, foliation or thin beds of rock that are less resistant to weathering than adjacent beds).

During this study, linear features were identified in the Bel Air and Jarrettsville quadrangles using standard aerial photographs (stereo pairs) and topographic maps (1:24,000). These data were supplemented by Landsat satellite imagery and side-looking radar imagery to identify a few larger-scale features (lineaments). The linear features were plotted on a quadrangle map. A well-location map at the same scale was superimposed on the map with the linear features in order to identify wells on linear features. Figure 9 shows the linear features identified in the Bel Air quadrangle. The Bel Air quadrangle contained 265 inventoried wells, of which 16 were located on identified linear features. The average yield of all wells in the quadrangle was 13.7 gal/min, whereas the average yield of wells on linear features was 51.1 gal/min. The Jarrettsville quadrangle contained 290 inventoried wells, of which 13 were identified as occurring on linear features. The average yield of all wells in the quadrangle was 7.6 gal/min whereas the average yield of wells on linear features was 21.6 gal/min.

Few wells in Harford County have been drilled on the identified linear features, chiefly because most linear features are in valleys or draws where houses are seldom constructed. Housing subdivisions are generally built in upland areas, where the land surface is fairly flat and conditions for constructing septic systems are most favorable.

During the study, three test wells were drilled in order to demonstrate that high-yielding wells can be obtained by drilling at sites selected on the basis of topography, linear features, or some known geologic feature such as the trace of a fault. All three test wells were drilled on linear features, two were in valleys, and one (HA-CC 142) was in a small draw along the trace of a mapped fault. The following table summarizes data from the three test wells:

Well number	Depth (ft)	Yield (gal/min)	Specific capacity [(gal/min)/ft]
HA-CA 23	200	35	1.67
HA-CC 142	200	28	.62
HA-CC 143	218	45	1.22

The yields and specific capacities of these test wells are not spectacular, but are substantially better than average for wells in the Piedmont.

Measurements of joint orientations were made at the Davis quarry (James Run Gneiss). These measurements were plotted on a frequency graph or rose diagram (fig. 10). Figure 10 shows that the joint system can be roughly

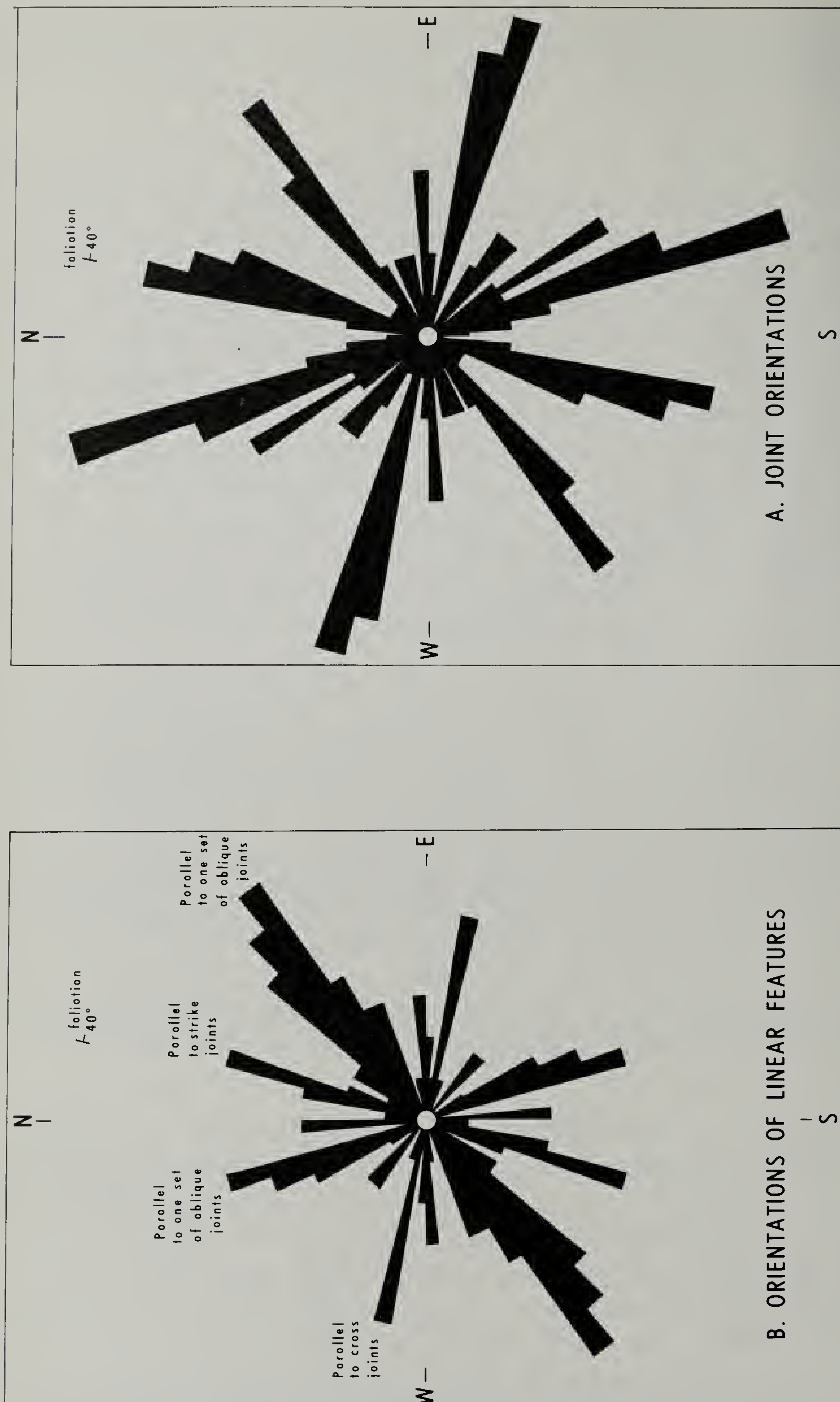

Figure 10.—Rose diagrams showing correlation between joints and linear features in the vicinity of the Davis quarry.

separated into four principal sets: One set of joints (strike joints) parallel to the strike of the foliation, one set of joints (cross joints) perpendicular to the strike of the foliation, and two complimentary sets of joints (oblique joints) roughly bisecting the angle between the strike of the cross joints and strike joints. In addition, there are possibly three minor joint sets (fig. 10). About half of the measurements were made in the quarry and half made along James Run immediately south of the quarry.

Using aerial photographs, linear features were identified within a circle with a radius of 1 mi around the Davis quarry. The orientations of the linear features were plotted in the same way the joint measurements were plotted (fig. 10). Comparison of the two rose diagrams in figure 10 indicates a correlation between the orientation of joints and linear features. This correlation strengthens the concept of drilling wells on mapped linear features to obtain high-yielding wells.

WATER USE

Ground-water use in Harford County, in 1974, was about 2,800 Mgal or 7.7 Mgal/d on the basis of pumpage records from large users and on population statistics from those users having individual wells. The major ground-water users and the quantities of water used by each are listed in table 3 of Nutter and Smigaj (1975). The estimated pumpage for self-supplied domestic users is based on 1974 population statistics in each of the six election districts. In each election district, the population served by municipal systems was subtracted from the total population to obtain the population served by individual wells. This figure was multiplied by 50 gal/d per person to obtain the estimated pumpage from individual wells.

Figure 11 shows the relative quantities of ground water pumped in 1974 by municipal, industrial, and domestic users; the relative pumpage from Coastal Plain aquifers and Piedmont aquifers; and a comparison of pumpage by municipal users.

In addition to the ground water used in Harford County, the town of Havre de Grace, the town of Bel Air, Aberdeen Proving Ground, and Edgewood Arsenal use surface-water supplies. In 1974, water use was about 11 Mgal/d in Harford County; about two-thirds of this was ground water and one-third surface water.

WATER QUALITY

Ground water in Harford County is generally of good chemical quality. The native ground water is a soft to moderately hard calcium magnesium bicarbonate type, with low dissolved solids and nearly neutral to slightly acid. In some places it may have objectionable concentrations of iron and manganese

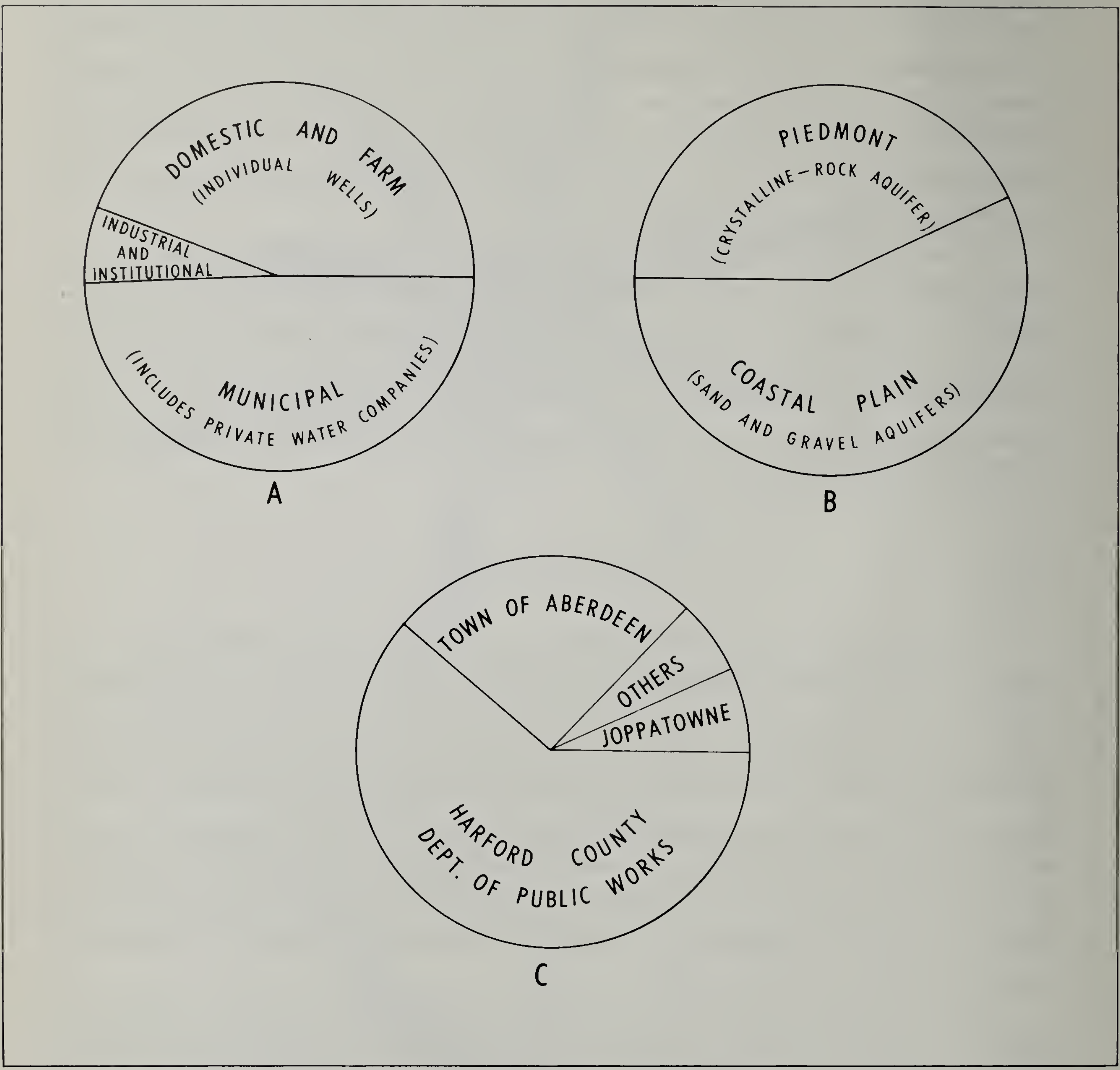

Figure 11.—Pie diagram showing ground-water use by (A) type of users, (B) geologic source, and (C) municipal systems.

and low pH. In addition, nitrate contamination may be a problem in a few isolated areas.

The chemical quality of ground water is related to the mineral composition of the soil and rock through which the water moves, the rate of movement through the aquifer, and the proximity to sources of contamination, such as sewage-disposal systems, barnyards, and fields where fertilizer has been applied.

During this investigation, 135 chemical analyses of ground-water samples were available for study (Nutter and Smigaj, 1975). In addition, more than 125 partial chemical analyses were obtained from the files of other government agencies and consultants.

The dissolved-solids concentration represents the quantity of dissolved mineral matter in a water sample. Figure 12 shows the relation between dissolved solids and specific conductance, a measure of the capacity of a solution to conduct an electric current. An approximation of the dissolved solids in a water sample can be made by measuring specific conductance in the field and reading the appropriate dissolved-solids concentration from the graph.

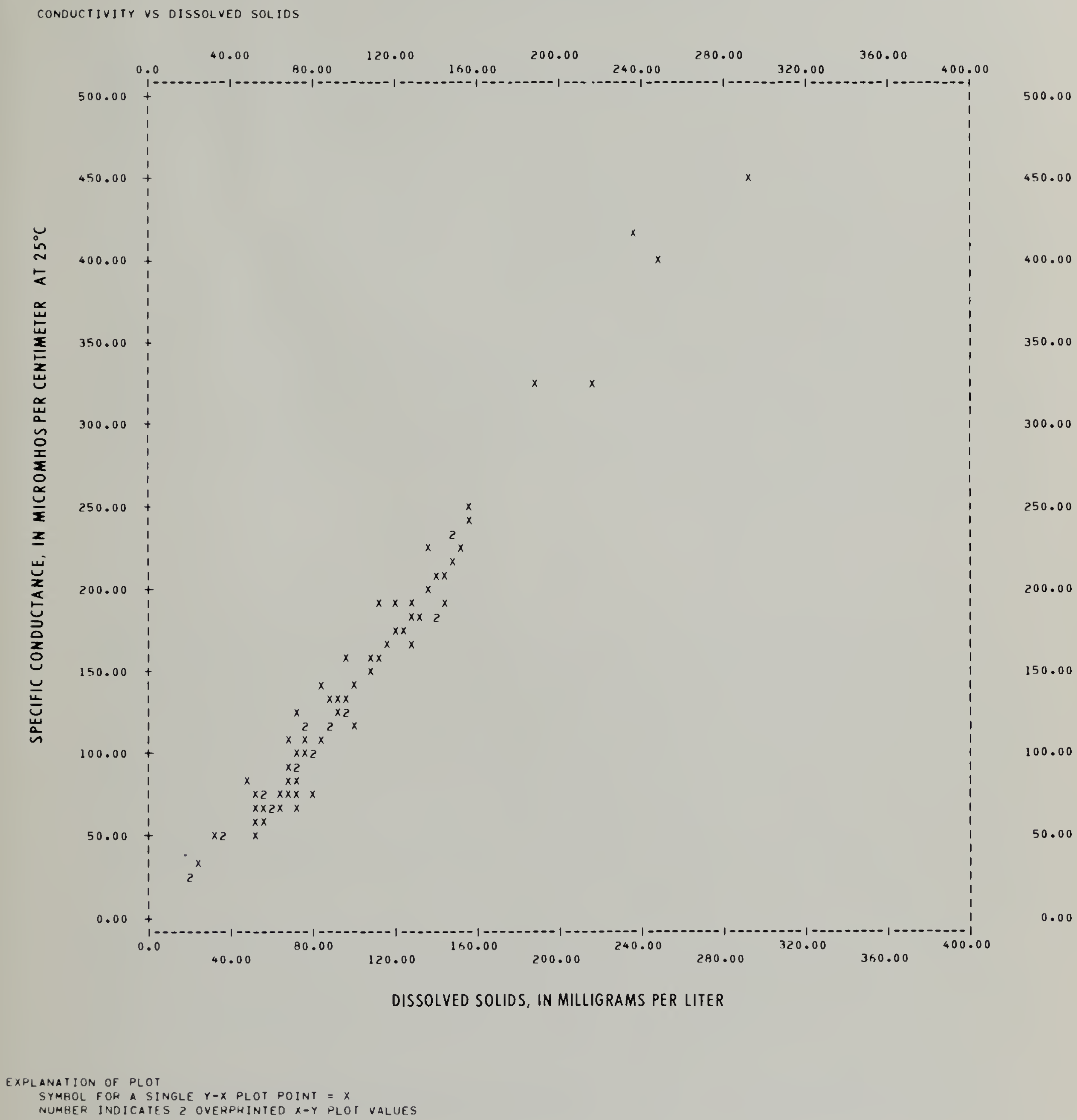

Figure 12.—Relation between specific conductance and dissolved-solids concentration in ground water in Harford County.

Several chemical constituents affect the use of water if present in excess of certain concentrations. The constituents and properties most likely to affect water use include iron, manganese, nitrate, sulfate, silica, chloride, fluoride, phosphate, hardness, dissolved solids, and hydrogen-ion concentration (pH). In Harford County, the constituents that most commonly cause water-quality problems are iron, manganese, nitrate, and hydrogen-ion concentration; these constituents are the only ones discussed in detail in this report.

Hydrogen-ion Concentration

The hydrogen-ion concentration of a water sample is indicated by the pH, which is the negative logarithm of the hydrogen-ion concentration, in moles per liter of water. PH is a measure of the extent to which the water sample is acidic or alkaline: a pH of 7 indicates a neutral condition, less than 7 acidic, and greater than 7 alkaline. Because the pH values are logarithmic, a water sample having a pH of 6 has 10 times the concentration of hydrogen ions as a sample having a pH of 7. Water having a low pH may corrode well casings, pumps, and plumbing fixtures and may dissolve copper, iron, or zinc from this equipment.

Slightly acidic ground water is one of the most common water-quality problems in Harford County. PH ranged from 5.3 to 10.2 (Nutter and Smigaj, 1975, p. 85, 86). Of the 135 analyses, pH of 60 percent of the samples was less than 7 and 34 percent less than 6.5. PH of 28 percent was greater than 7 and only 6.7 percent greater than 7.5.

Iron

Iron is a common element in nature, but is generally dissolved in ground water in only small concentrations. Water becomes unsuitable for most uses by the presence of only a few hundred micrograms per liter (μg/L)[1] of iron. Concentrations of as little as 300 μg/L, although not harmful to health, can cause reddish-brown stains on white porcelain or enamelware and on clothing washed in the water; concentrations greater than 1,000 μg/L can cause clogging of pumps and plumbing fixtures. The National Academy of Sciences—National Academy of Engineering (1972) recommends that no more than 300 μg/L should be present in a water supply.

Twenty-four percent of the samples analyzed (Nutter and Smigaj, 1975) contained iron exceeding 300 μg/L. Iron concentration ranged from 0 to 13,000 μg/L, although, at a few sites, some of the iron may have been dissolved from the well casing or the plumbing system.

The most common form of iron in solution in ground water is the ferrous ion (Fe^{++}); ferric iron (Fe^{+++}) normally precipitates as $Fe(OH)_3$, but iron can

[1] Iron and manganese are reported in micrograms per liter (1 mg/L = 1,000 μg/L).

occur as several different complex ions. The stability of various iron species are shown in figure 13. A stability-field diagram is constructed by plotting pH against Eh (oxidation potential). Eh is a measure of the tendency of a particular chemical species to be oxidized. Eh is obtained by measuring the electrical potential between a calomel electrode and a noble-metal electrode (Back and Barnes, 1965, p. 3). The pH of most natural ground water ranges between 4 and 9, and Eh probably ranges between -100 and +700 millivolts, based on studies by Back and Barnes, 1965. Therefore, several of the species shown on figure 13 are not stable under ordinary conditions; the stability field for most ground water is shown in the unshaded central part of figure 13. Within the range of pH likely to be found in Harford County, the solubility of ferrous iron increases with decreasing Eh.

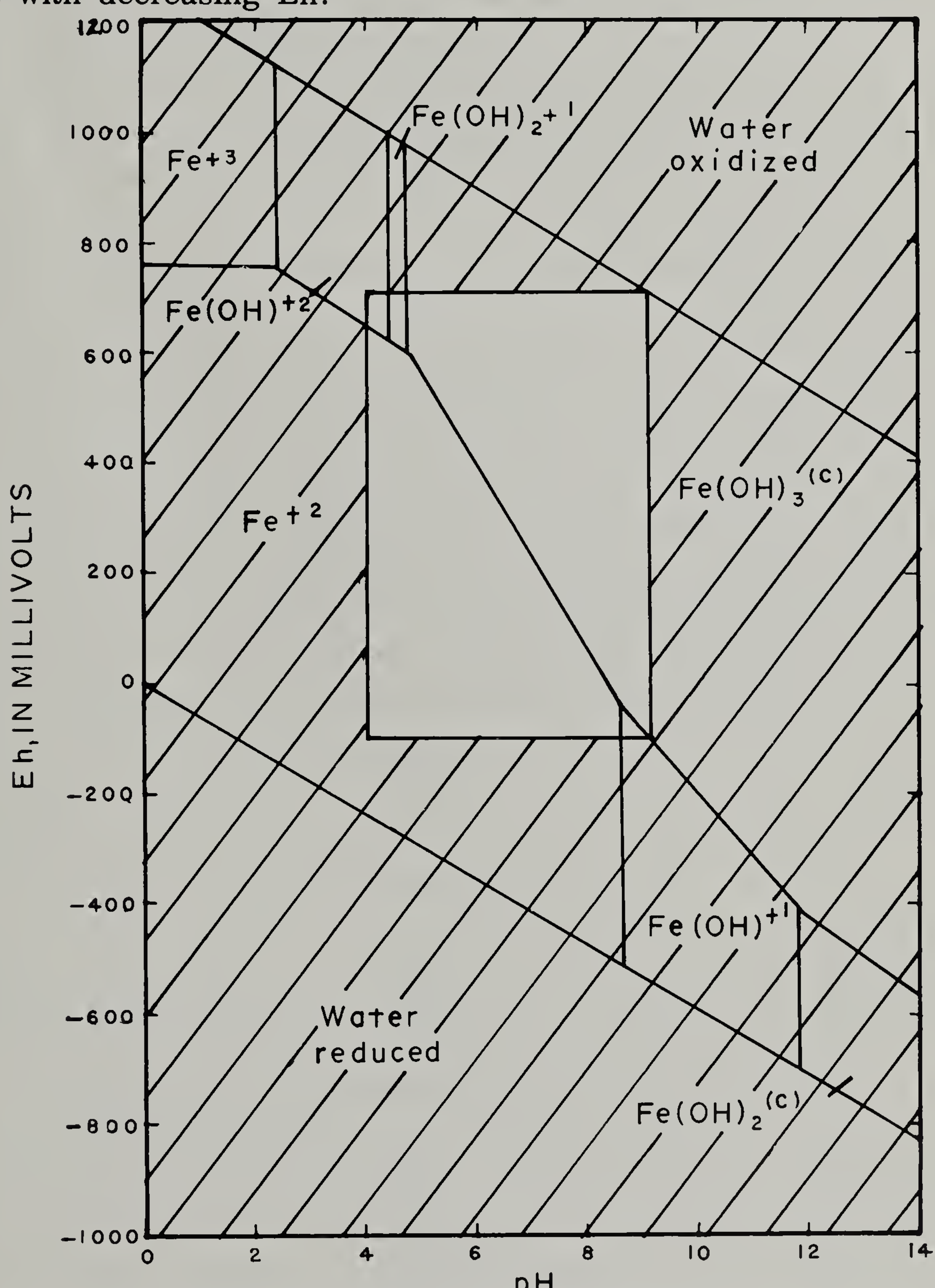

Figure 13.—Stability-field diagram for aqueous ferric-ferrous system. Central area represents the stability field for most ground water. Adapted from Hem and Cropper, 1959.

Back and Barnes (1965) found that in Coastal Plain deposits in Anne Arundel County, Md., there was a correlation between Eh and the concentration of iron. The higher concentrations of iron occurred in waters with the lowest Eh values (low Eh indicates reducing conditions, high, oxidizing). They measured the highest Eh values in water from shallow wells and wells in recharge areas, the lowest in wells farthest downgradient in water associated with gray and green sediments.

The distribution of serious iron problems is erratic and, in some places, difficult to explain. In general, iron problems seem to be more serious in lowland or marshy areas of prevailing reducing conditions, which permit the iron to remain in solution (ferrous ion). Iron problems are less common in upland areas, where recharge water contains abundant oxygen, apparently because iron does not go into solution under oxydizing conditions (fig. 13). However, iron chemistry is extremely complex and, in addition to Eh and pH, is influenced by the presence of various iron bacteria, the amount of organic matter in the aquifer, and the concentration of bicarbonate and various sulfur species.

Green Spring Hills and Kenwood Farms, subdivisions near the Fall Line, illustrate the variability of iron with depth. The subdivisions are in areas having a veneer of Potomac Group sand and clay. Water from drilled wells tapping crystalline rocks underlying the Coastal Plain deposits nearly always has high concentrations of iron, with the exception of water from a few shallow drilled wells. Because of the iron problems in drilled wells, most homes in the subdivisions have shallow augered wells, 3 ft in diameter cased with concrete curbing. These wells yield water having fairly low concentrations of dissolved iron, apparently because dissolved oxygen in the water precipitates iron in the aquifer or in the well as $Fe(OH)_3$. The following table shows depth and dissolved iron concentrations in well water from the subdivisions:

Well number	Depth (ft)	Iron concentration ($\mu g/L$)
	Drilled wells	
HA-DC 45	100	5,600
HA-DC 55	198	7,200
HA-DC 76	190	13,000
	Augered wells	
HA-DC 49	29	60
HA-DC 50	40	100
HA-DC 51	44	80
HA-DC 53	35	20
HA-DC 74	30	90
HA-DC 81	35	30

Manganese

Manganese is a minor constituent in natural water and is rarely present in concentrations exceeding 100 μg/L. Water is made unsuitable for most uses by the presence of less than 200 μg/L manganese. Concentrations of as little as 50 μg/L can cause dark-brown or black stains on clothing or porcelain fixtures. The National Academy of Sciences—National Academy of Engineering (1972) recommends that no more than 50 μg/L should be present in a water supply.

Ground water containing more than 50 μg/L manganese is fairly common in Harford County. Twenty-six percent of the samples analyzed by the U.S. Geological Survey contained manganese exceeding the recommended limit. In addition, most of the more than 100 analyses from the supply wells at the community of Joppatowne, analyzed by privately owned laboratories, contained more than 50 μg/L manganese.

The high concentration of manganese in the Joppatowne water supply is apparently related to brackish-water intrusion into the aquifer tapped by most of the wells in that community's well field. Intrusion of brackish water may have been induced by pumping at the community well field during and after the dredging of a nearby marina a few years after the construction of the community had begun.

The community of Joppatowne, adjacent to the tidal part of the Gunpowder River in southwestern Harford County, was established in 1962, and expansion continued for several years. In late 1967, a marina was dredged and subsequently townhouses were constructed with each home having private docking facilities along a dredged canal. The water supply was initially obtained from three wells screened in the Potomac Group sands between a depth of 60 and 165 ft. Joppatowne is near the Fall Line, and the overlapping Potomac Group sand and clay beds are generally less than 200 ft thick.

Intrusion of the brackish water itself was not a serious problem, even though the chloride content changed from 6 mg/L, before 1967, to 360 mg/L in at least one well in November 1971. The finished water (a mixture from several wells) did not exceed the recommended limit for chloride of 250 mg/L (National Academy of Sciences—National Academy of Engineering, 1972). However, the increase in chloride content was accompanied by a rapid increase in manganese content (fig. 14). There is no reason to believe that increased concentration of chloride caused the increase in manganese concentration; the chloride may be an indicator of geochemical conditions that gave rise to the increase in manganese concentration. The increased concentration of chloride strongly suggests induced infiltration of brackish water from the Gunpowder estuary which may have simply been the result of increased pumpage from the well field, but the timing of the dredging and the rise in chloride concentration a few months later suggests a correlation between these two events.

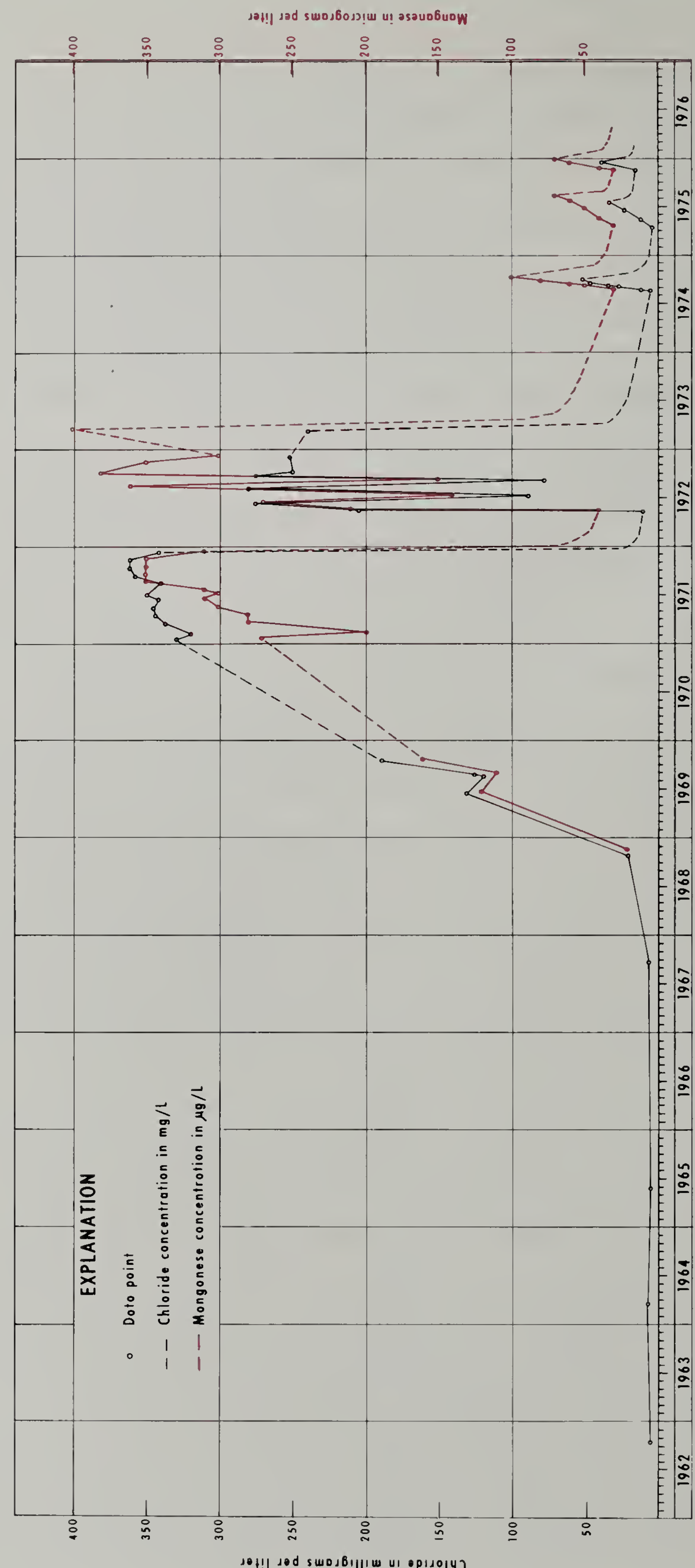

Figure 14.—Changes in chloride and manganese concentration with time in well HA-EC 13 in the Joppatowne well field.

The details of the brackish-water intrusion are beyond the scope of this discussion, but they illustrate an apparent relationship between the increase in chloride and the increase in manganese in the Joppatowne water supply. The highest manganese concentration (650 μg/L) was recorded in November 1972 in well HA-EC 14, 1,500 ft from the dredged area. In 1972, a new well, 2,200 ft from the dredged area, became the principal source of water for the community. After the new well was put into service, the other wells were pumped on a rotating basis. When the old wells are not pumped for a month or two, the chloride and manganese levels drop substantially (fig. 14), as the natural water-table gradients toward the river are reestablished, and the brackish water is flushed out of the aquifer in the vicinity of the wells. However, when pumping resumes, the water-table gradients are reversed, and chloride and manganese levels in the well water begin to increase again.

The increase in manganese as the wells in the Joppatowne well field are pumped may be due to reductions in the dissolved oxygen in the water as it moves through organic-rich mud in the estuary floor. Somewhat similar conditions have been demonstrated in Rhode Island (Johnston and Back, 1977, p. 322); however, this theory has yet to be proved in Joppatowne.

Nitrate

Nitrate is normally present in small quantities in ground water, but concentrations of more than a few milligrams per liter may indicate contamination from septic-tank effluent, barnyard wastes, or nitrate fertilizers. Most nitrate in uncontaminated ground water is derived from the decomposition of organic matter in the soil, inasmuch as minerals containing nitrogen are generally absent in most rocks. Nitrogen is an essential part of living organisms, and nitrate is the final product of oxidation in the nitrogen cycle.

Several medical studies have indicated that drinking water containing more than 45 mg/L nitrate[1] may contribute to or be in the main cause of a condition in infants known as methemoglobinemia (infant cyanosis). Methemoglobinemia is a disease characterized by certain specific blood changes that inhibit the carrying of oxygen in the blood and, in infants, may be caused by high nitrate in water used for preparing the feeding formula. Therefore, water containing more than 45 mg/L nitrate should not be used for infant feeding (National Academy of Sciences—National Academy of Engineering, 1972).

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[1] 45 mg/L nitrate reported as NO_3 is equivalent to 10 mg/L nitrate reported as N. In this report all nitrate values are reported as NO_3.

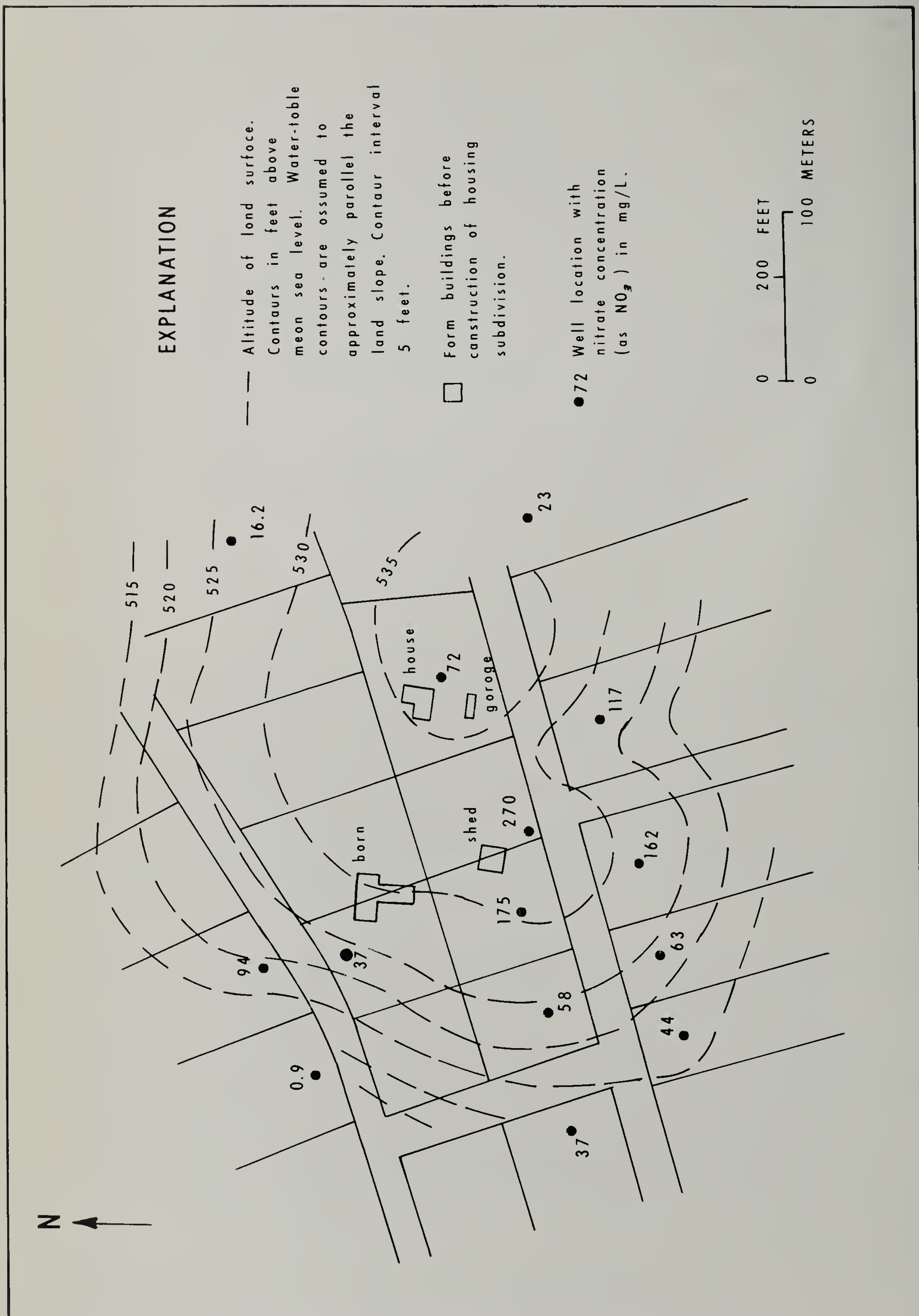

Figure 15.—Distribution of nitrate in ground water in a housing subdivision near Fallston, Md. (data from Harford County Health Department).

The nitrate concentrations in water samples collected during this study ranged from less than 0.0 to 98 mg/L. The mean concentration was 18.3 mg/L and the median 7.0 mg/L. Less than 5 percent of the analyses exceeded the recommended limit. However, a somewhat higher percentage of the analyses in the files of the Harford County Health Department exceeds the recommended limit, but the sample population may be biased because of the tendency to collect a larger proportion of samples from problem areas. Several areas identified as having high nitrate concentrations are near abandoned barns and feedlots. The source of the nitrate contamination may be animal wastes in the soil at these sites (Whitlock, 1977). One such case is illustrated in figure 15. The nitrate concentration is greatest in an area that appears to have been a feedlot adjacent to the former location of a barn; the nitrate concentration decreases downslope, apparently due to dilution and dispersion.

SUMMARY

Moderate to large ground-water supplies can be obtained from wells in nearly all areas underlain by Coastal Plain deposits composed of sand and gravel. The Piedmont aquifers are composed of igneous and metamorphic rocks in which water is transmitted through complex and varied fracture systems. Wells in the Piedmont aquifers can provide small to moderate water supplies in all sections of the county, although some areas have a significant percentage of wells whose yields are inadequate for household use.

Well yields in the Coastal Plain aquifers are governed by the permeability, thickness, and lateral extent of the sand and gravel beds in which the wells are screened. In addition, well yields in the Coastal Plain aquifers depend on well-construction factors, such as length of screen, type of screen, diameter of well, placement of screen within the sand bed, and proper development.

Well yields in the Piedmont aquifers are governed by geologic structure (joints, faults, cleavage, foliation); topographic position of the well; lithology; thickness of the saprolite; and well depth.

Well-yield data are biased on the low side because most of the records are for domestic wells, which require only a few gallons per minute and therefore seldom yield their maximum potential. In addition, many domestic wells are drilled in unfavorable locations on hilltops and uplands. On the other hand, wells drilled in valleys and draws or along linear features identified on aerial photographs have much higher average yields than randomly located wells. The valleys and linear features apparently represent permeable fracture zones in the rock and therefore are favorable sites for obtaining high-yielding wells.

The chemical quality of the water in both the Coastal Plain and the Piedmont aquifers is generally good. The most common water-quality problems are high concentrations of iron and low pH. In addition, high concentrations of manganese occur in a few areas in the Coastal Plain, and nitrate

exceeding the limit recommended by the Environmental Protection Agency occurs in a few areas in the Piedmont.

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[1] The name of this agency was changed to the Maryland Geological Survey in June 1964.

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GROUND-WATER DATA

The well records contained in table 3 include only those wells for which information was obtained after publication of Nutter and Smigaj (1975). The locations of the wells included in table 3 are shown on figure 16.

Several geophysical logs are included in figure 17 for those readers interested in specific geologic and hydrologic data. The locations of the wells in which these geophysical logs were run are shown in figure 16 and in Nutter and Smigaj (1975).

Gamma-ray logs are useful for identifying the lithology of the formations penetrated by a well. The intensity of natural gamma-ray radiation increases to the right on the logs in figure 17. The principal source of natural gamma radiation in the Harford County Coastal Plain deposits is the potassium 40 isotope. Therefore, because clay contains abundant potassium, deflections to the right normally indicate clay and deflections to the left indicate clean sand that is likely to yield water to wells.

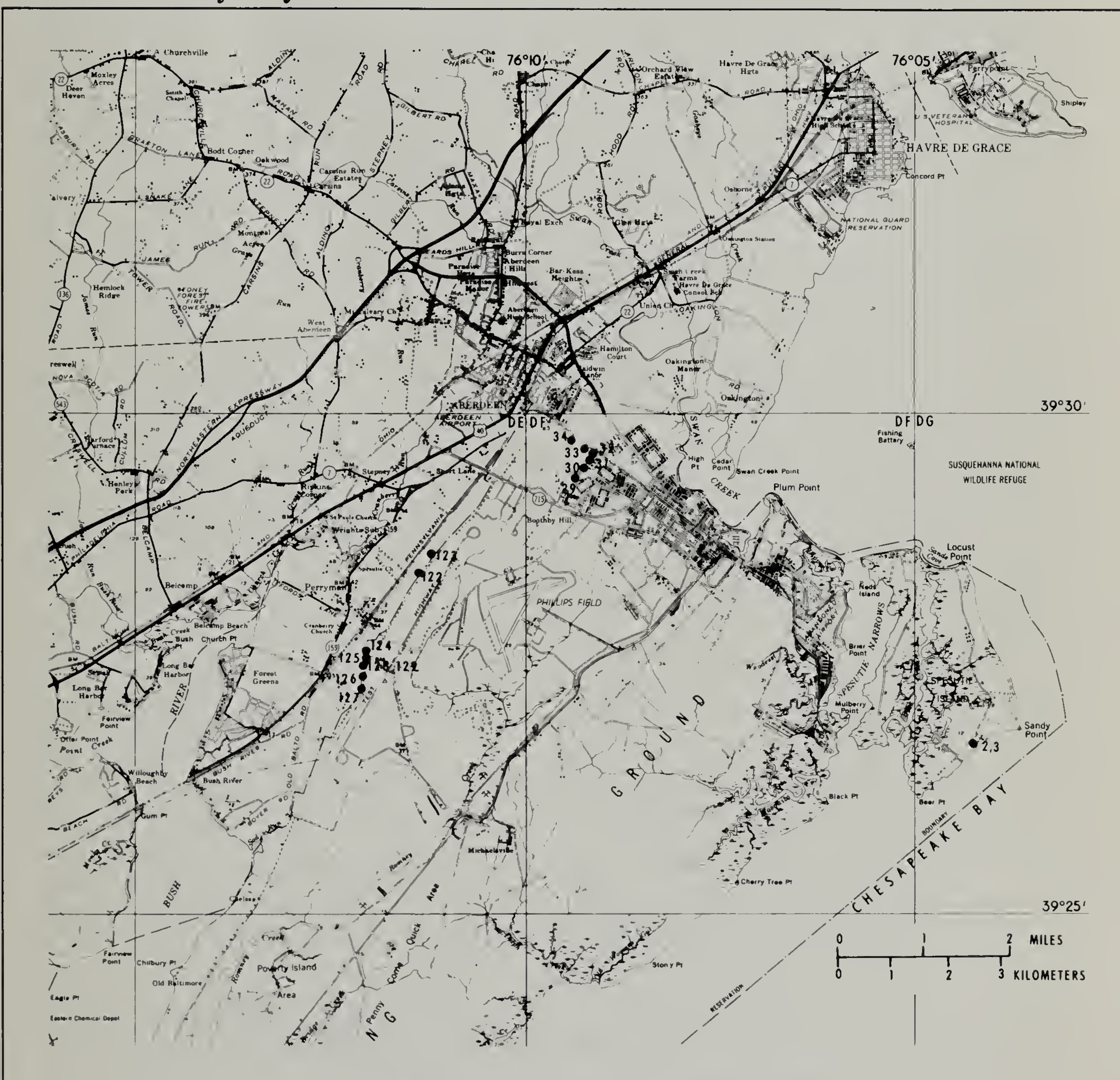


Figure 16.—Well locations.

Table 3.—Well Records in Harford County (not previously published).

Well number	Owner	Driller	Diameter (inches)	Year completed	Depth (feet)	Altitude of land surface (feet)	Static level (below land surface) (feet)	Pumping level (below land surface) (feet)	Yield (gal/min)	Specific capacity [(gal/min)/ft]	Aquifer	Remarks
HA-DE 122	Harford Co. Dept. of Public Works	Shannahan Artesian Well Co.	4	1970	116	40	—	—	—	—	Talbot Formation	Test hole
HA-DE 123	do	do	4	1970	87	35	—	—	—	—	do	do
HA-DE 124	do	do	4	1976	328	30	19.0	25.8	57	8.4	Potomac Group	Test well
HA-DE 125	do	do	4	1976	233	40	19.0	30.0	20	1.8	do	do
HA-DE 126	do	do	4	1976	253	30	18.7	30.0	17	1.5	do	do
HA-DE 127	do	do	4	1976	296	35	13.0	20.0	10	1.4	do	do
HA-DE 128	do	do	4	1976	65	40	13.5	15.8	38	16.5	Talbot Formation	do
HA-DE 129	do	do	4	1976	248	40	17.4	24.2	56	8.2	Potomac Group	do
HA-DF 29	Town of Aberdeen	do	4	1976	64	65	29.0	30.2	20	25.0	Talbot Formation	do
HA-DF 30	do	do	4	1975	80	65	33.2	34.1	30	33.3	do	do
HA-DF 31	do	do	4	1975	72	65	38.9	40.0	15	13.6	do	do
HA-DF 32	do	do	4	1975	64	55	34.0	38.0	10	2.5	do	do
HA-DF 33	do	do	4	1975	75	55	30.5	32.5	14	7.0	do	do
HA-DF 34	do	do	4	1975	42	55	32.0	33.0	0.5	0.5	do	do
HA-DG 2	Maryland Geological Survey	Sprague & Henwood, Inc.	6	1976	88	5	—	—	—	—	do	Core hole
HA-DG 3	do	do	3	1976	777	5	—	—	—	—	Potomac Group	do (Geoph. logs to 767 ft)

Type log: Gamma ray

Owner: Harford Co. Dept of Public Works

Driller: Shannahan Artesian Well Co.

Well No: HA-DE 124

Aquifer: Potomac Group

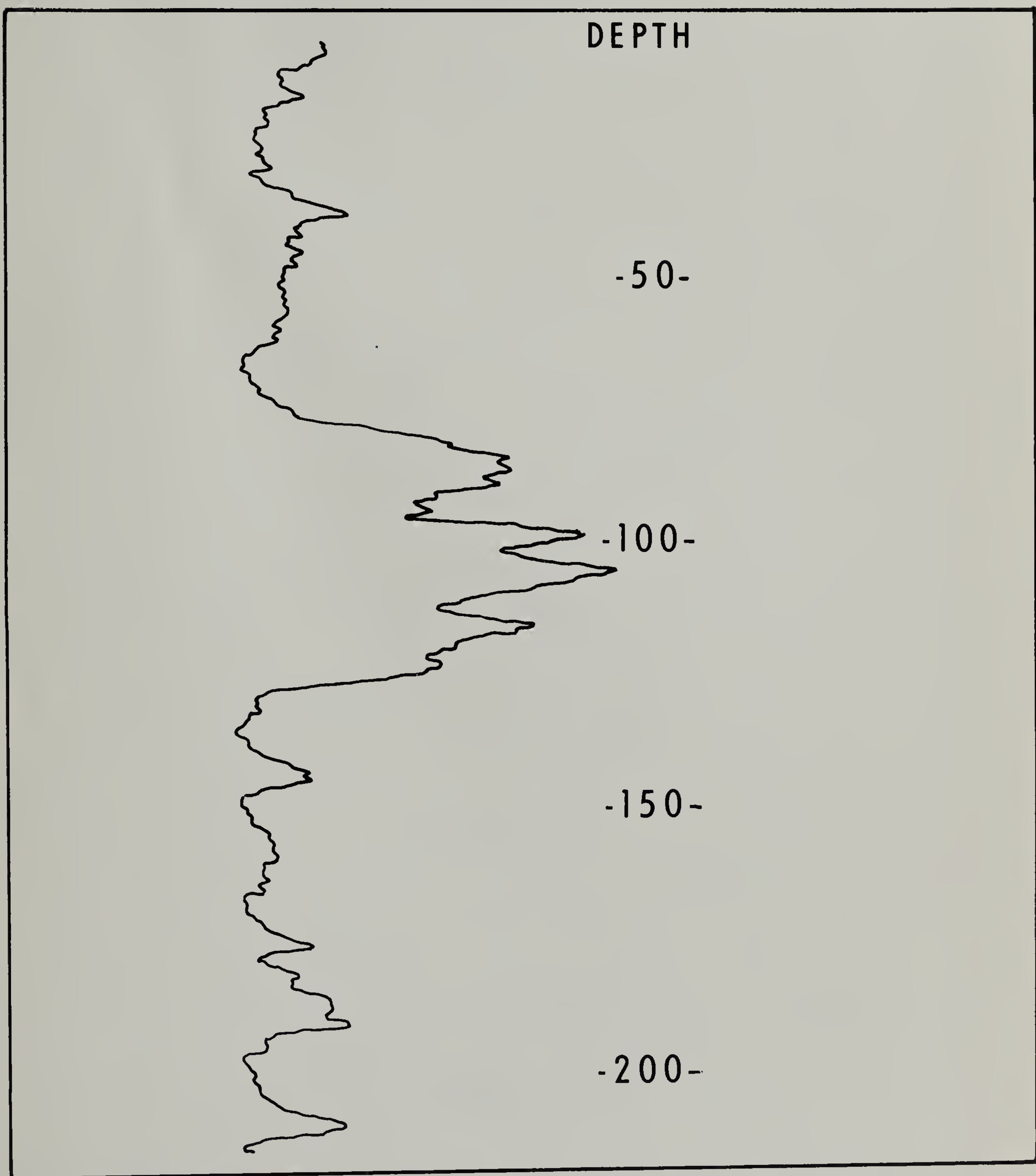


Figure 17.—Selected geophysical logs.

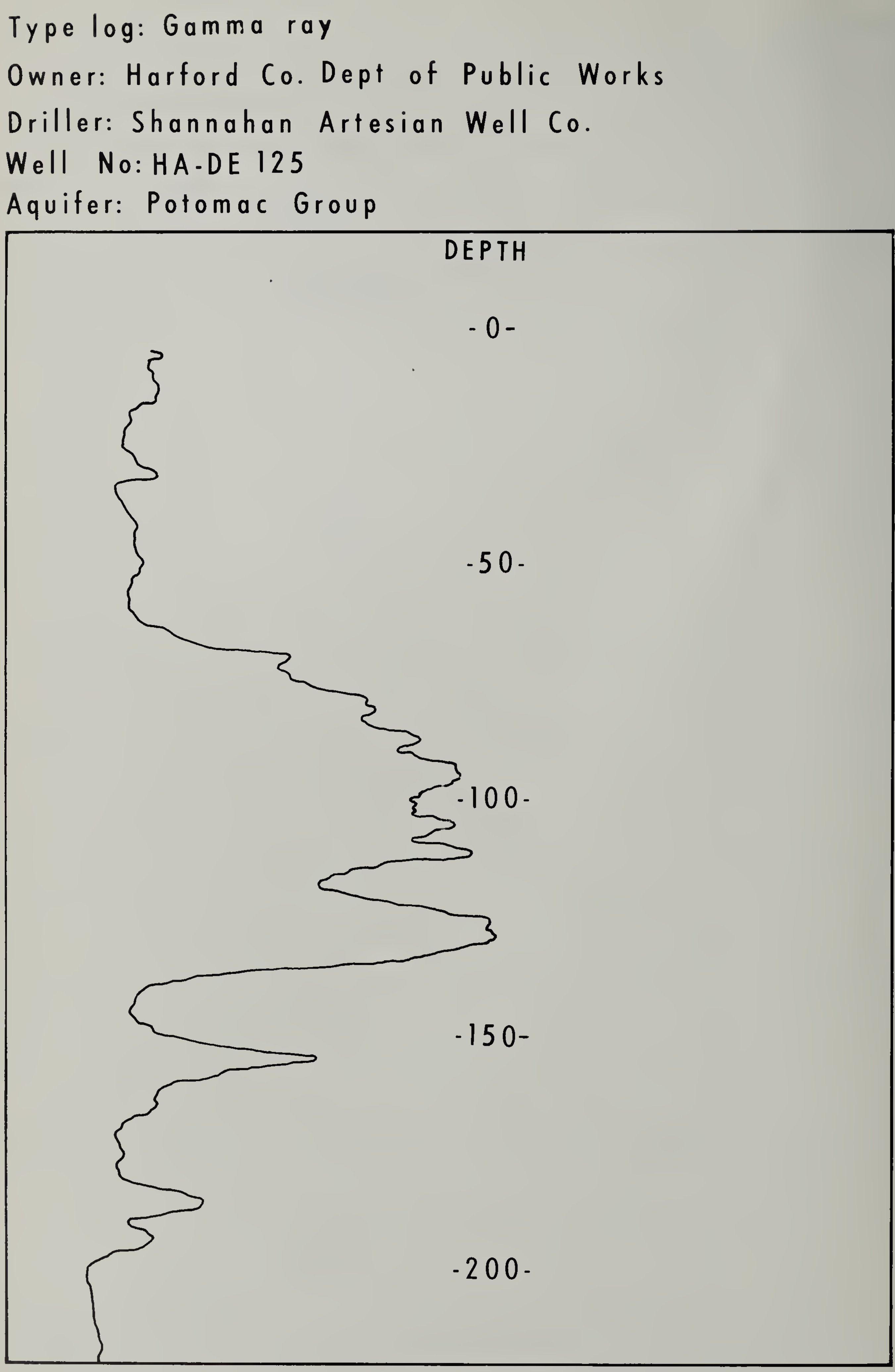


Figure 17.—Selected geophysical logs, continued

Type log: Gamma ray

Owner: Harford Co. Dept of Public Works

Driller: Shannahan Artesian Well Co.

Well No: HA-DE 127

Aquifer: Potomac Group

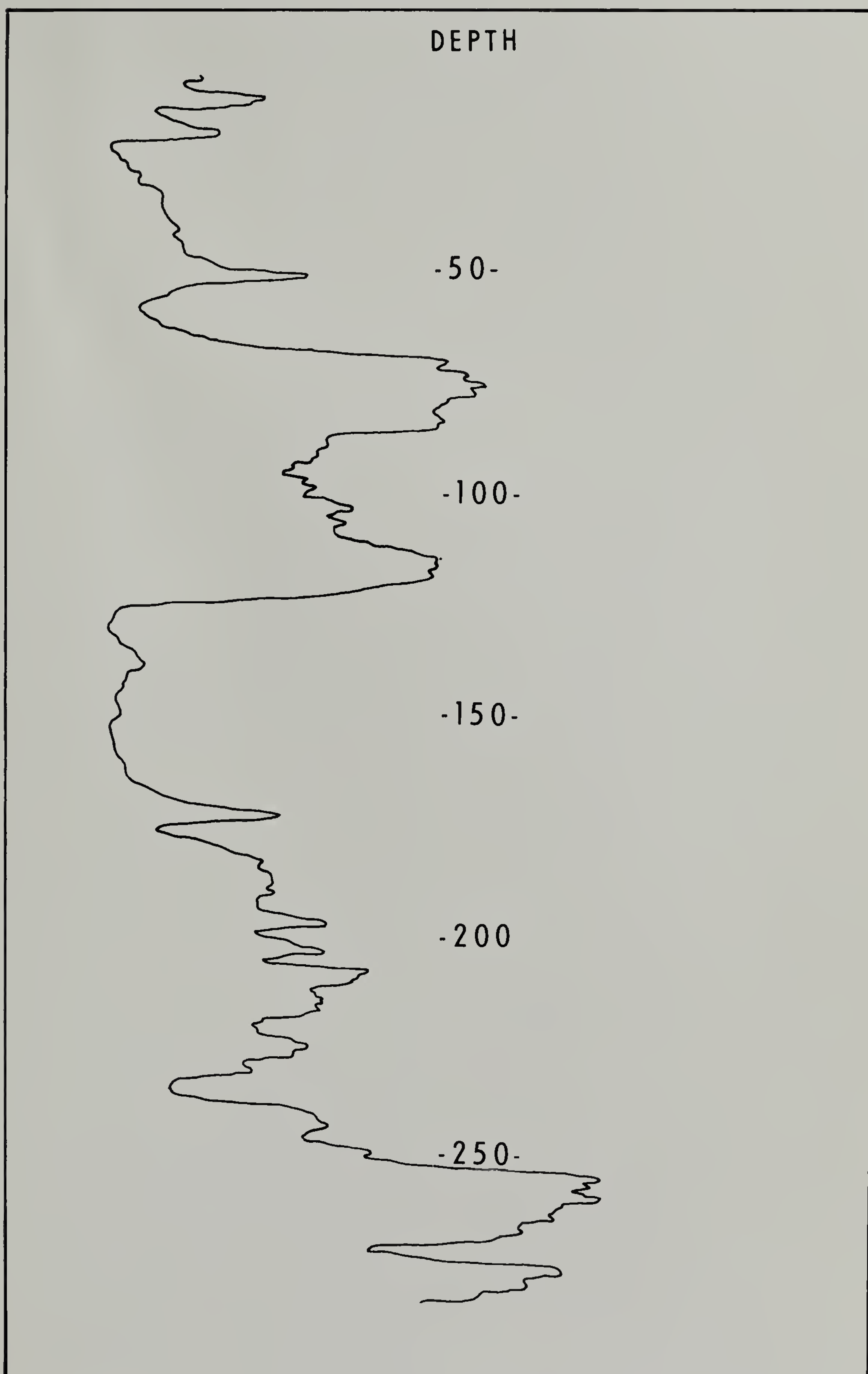


Figure 17.—Selected geophysical logs, continued

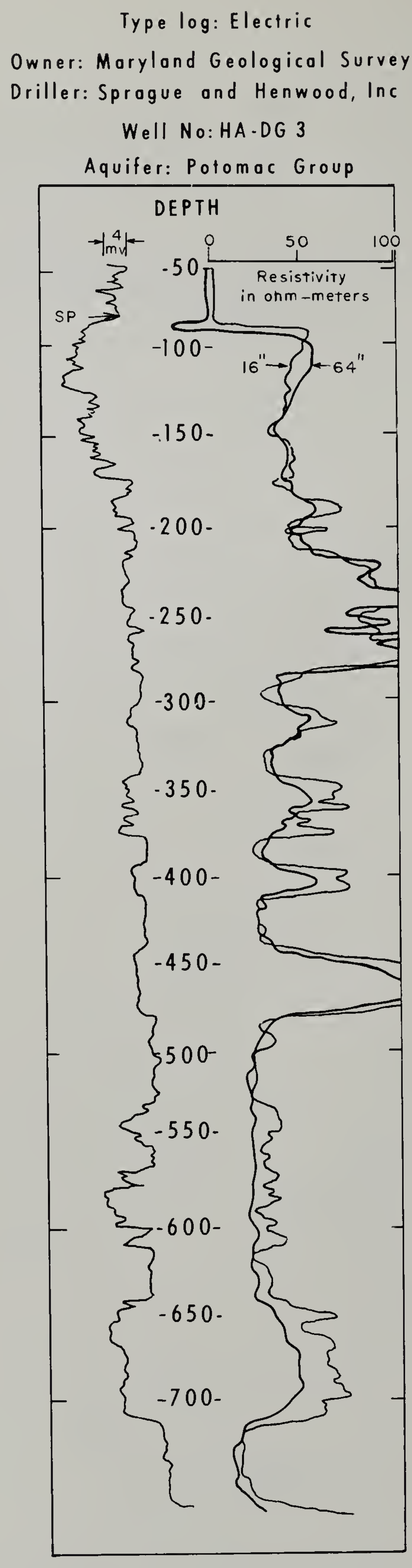


Figure 17.—Selected geophysical logs, continued

5763 II NW
(CONOWINGO DAM)

BEL AIR QUADRANGLE
MARYLAND—HARFORD CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

SE/4 BEL AIR 15′ QUADRANGLE

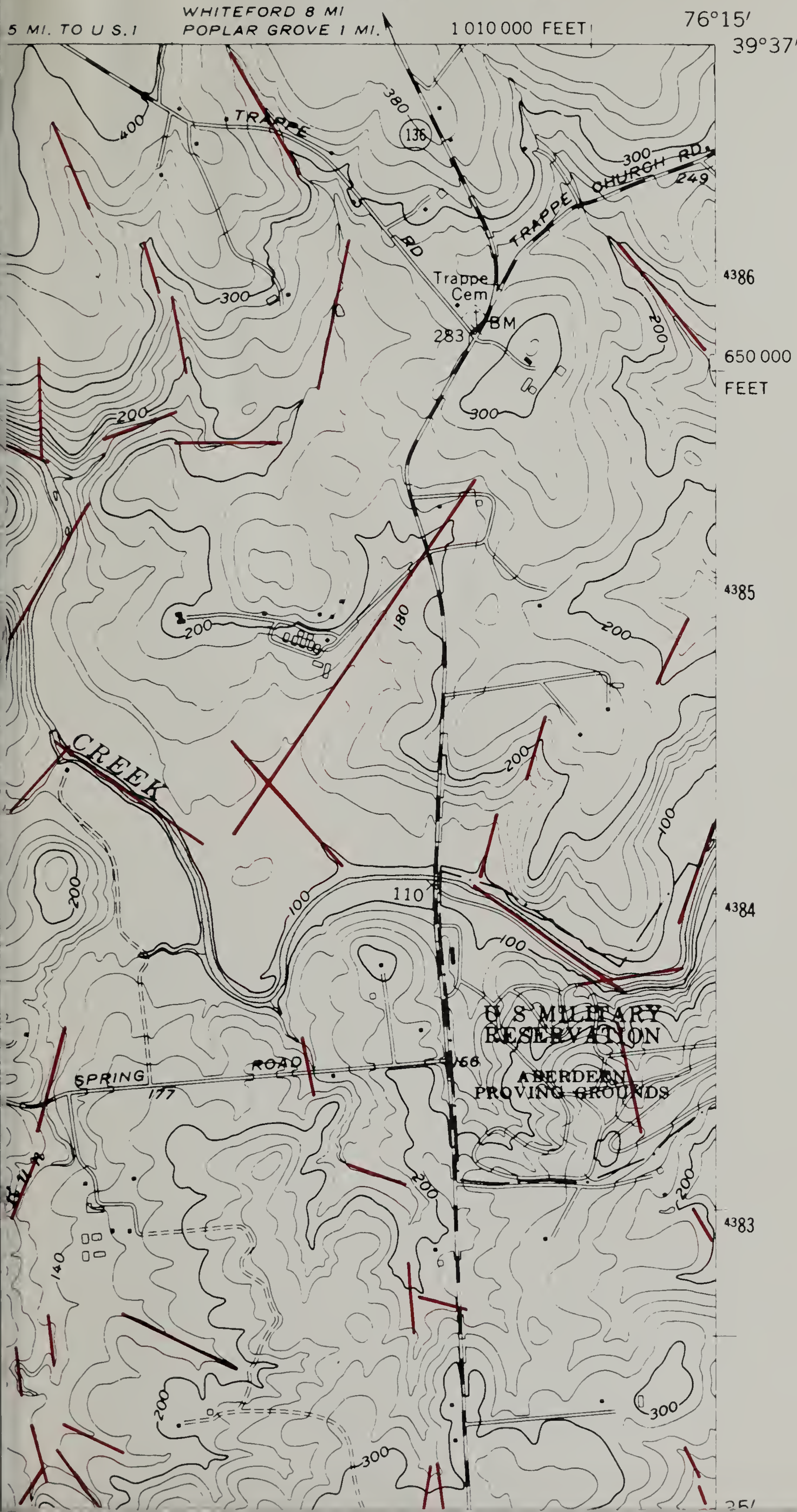
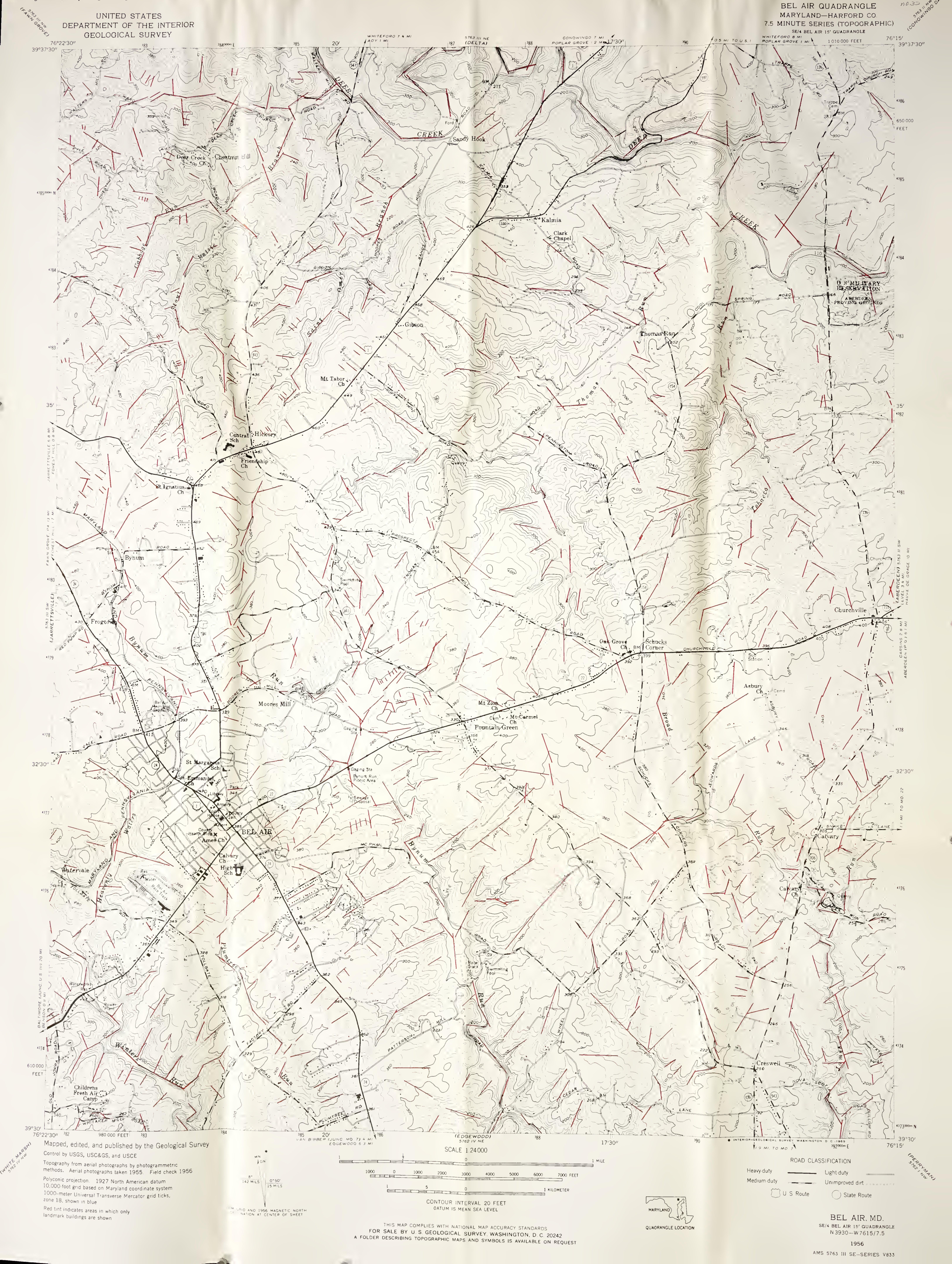


Figure 9.—Bel Air quadrangle showing linear features.



N

qual thickness
tal Plain deposits
Approximately located.
100 ft (30 m).

Coastal Plain
(Fall Line)

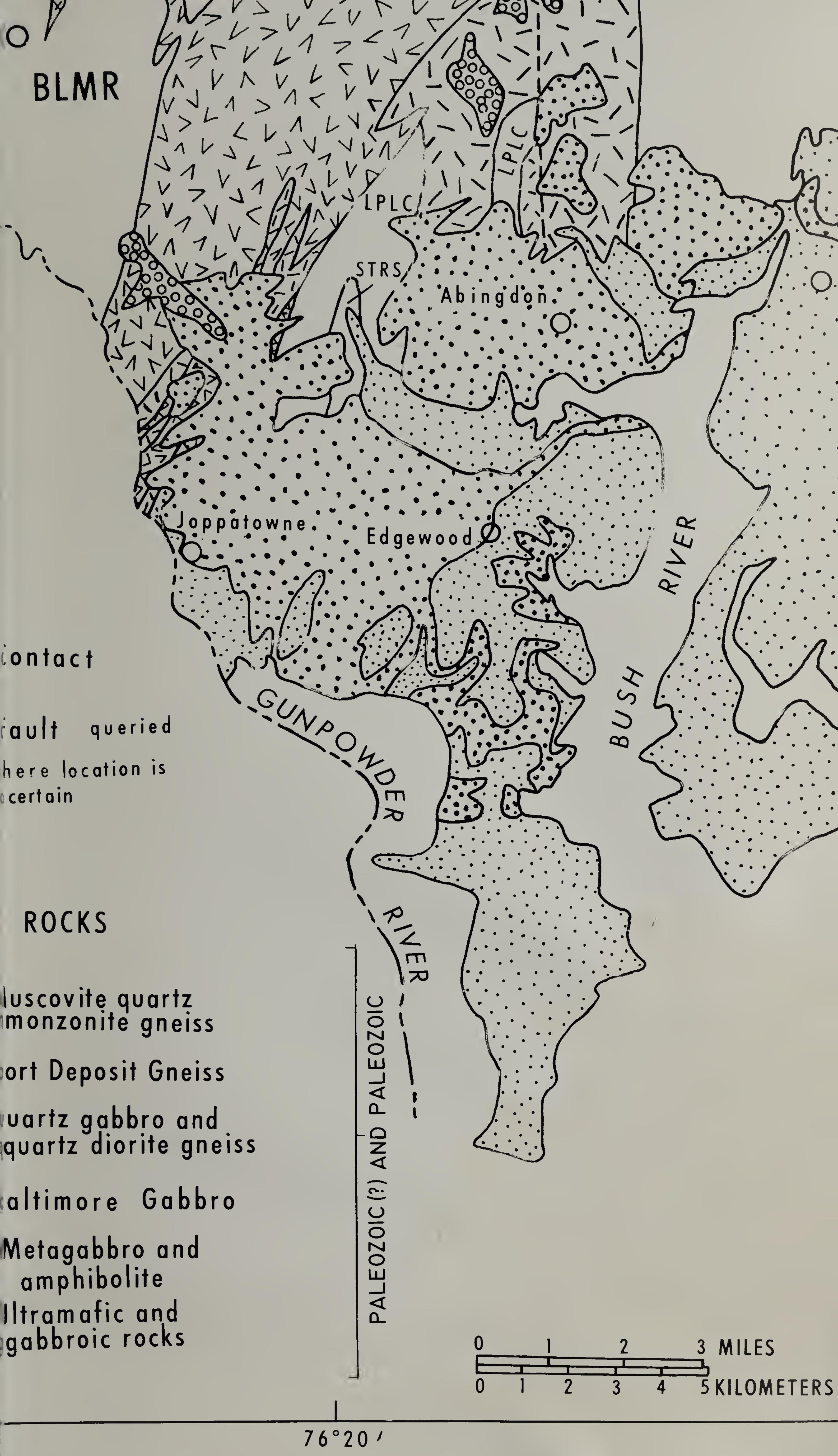
int and thickness

2 MILES
2 3 KILOMETERS

39°20′

76°00′

Figure 5.—Thickness of Coastal Plain deposits.



BLMR
LPLC
LPLC
STRS
Abingdon
Joppatowne
Edgewood
BUSH RIVER
GUNPOWDER RIVER
ontact
ault queried
here location is
certain
ROCKS
luscovite quartz
monzonite gneiss
ort Deposit Gneiss
uartz gabbro and
quartz diorite gneiss
altimore Gabbro
Metagabbro and
amphibolite
Iltramafic and
gabbroic rocks
PALEOZOIC(?) AND PALEOZOIC
0 1 2 3 MILES
0 1 2 3 4 5 KILOMETERS
76°20′

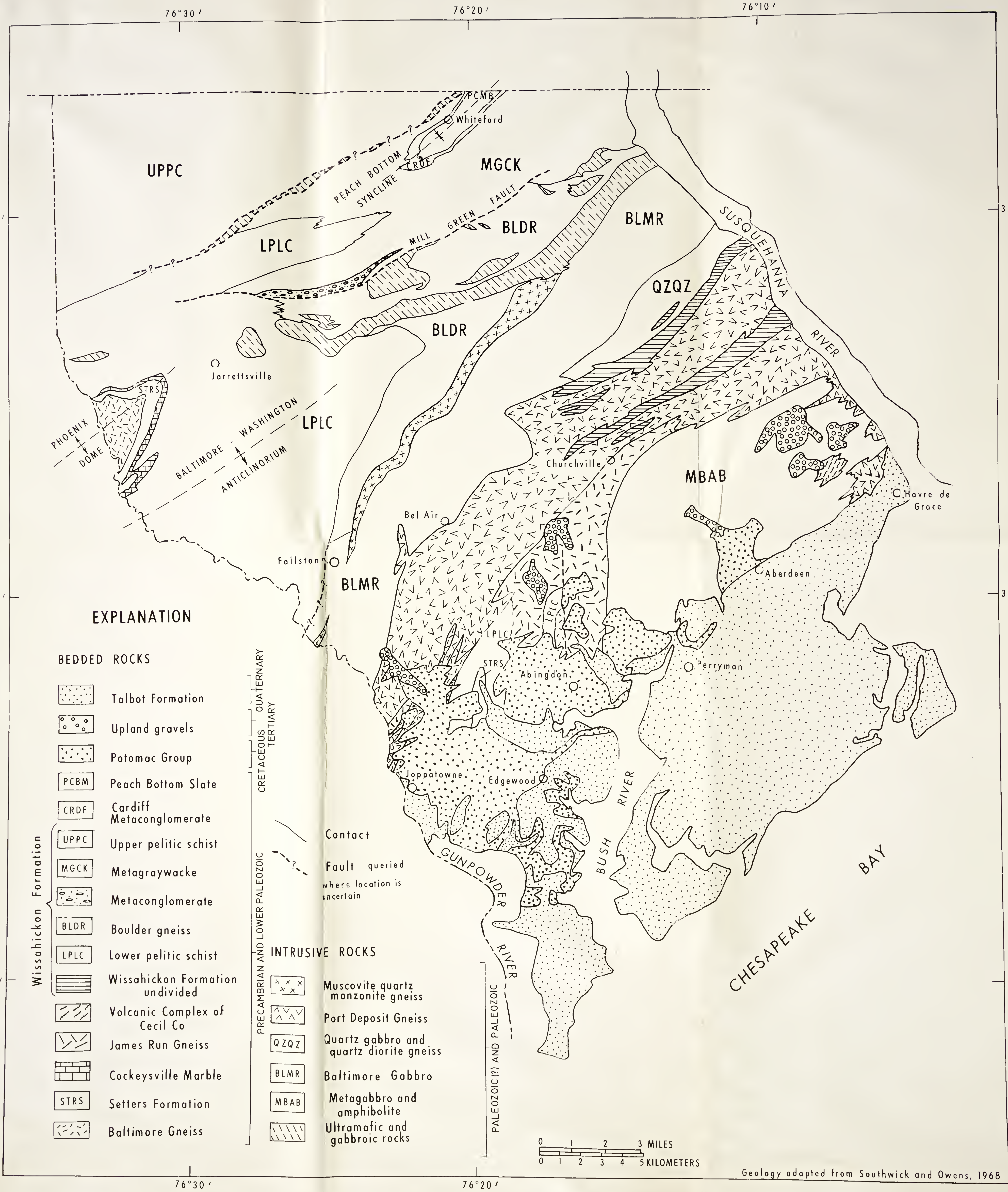


Figure 2.—Geologic map of Harford County.